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COMPUTER AUTOMATED ULTRASONIC INSPECTION SYSTEM

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06 FEBRUARY 1985

FINAL REPORT for PERIOD MARCH, 1979 - JULY, 1984

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NOTICE

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Standard ultrasonic inspection techniques used in industry today can involve tedious manual or semi-automated operations that make them incompatible with high-rate industrial production inspection requirements. However, advances in this technology and the rapid integration of this technology into both laboratory and production environments have made the development of computer-aided ultrasonic inspection a reality.

FOREWORD

This Final Report was prepared under Contract F33615-78-C-5205, Computer-Automated Ultrasonic Inspection System Production Demonstration for the F-16. The work was administered under the technical direction of Mr. Ed Wheeler of the Metals Branch, Manufacturing Technology Division (MLTM) Air Force Wright Aeronautical Laboratory, Wright-Patterson Air Force Base, Ohio.

The contractor is General Dynamics Fort Worth Division. Mr. G. J. Melven was program manager. D. K. Reid and G. J. Melven were the authors of this Final Report.

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LIST OF ABBREVIATIONS

CAUIS	Computer-Automated Ultrasonic Inspection System
FET	Field Effect Transistor
EPROM	Erasable Programmable Read Only Memory
I/O	Input/Output
PCA	Printed Circuitboard Assembly
RAM	Random Access Memory
RF	Radio Frequency
ROM	Read Only Memory
NET	Nondestructive Evaluation Terminal
SIC	System Interface Cabinet
DMA	Direct Memory Access
BCM	Bridge Control Microcomputer
CRT	Cathode Ray Tube
SBC	Single Board Computer

1.0 INTRODUCTION

1.1 Background

Standard ultrasonic inspection techniques used in industry today can involve tedious manual or semi-automated operations that make them incompatible with high-rate industrial production inspection requirements. But with advances in digital computer technology and the rapid integration of this technology into both laboratory and production environments, the development of computer-aided ultrasonic inspection has become a reality. By reducing inspection costs through reduced inspection time, decreased inspector interaction, as well as providing more efficient inspection record storage and retrieval, these automated systems are proving their value and indispensability in the manufacturing environment. Computer-automated ultrasonic inspection has the potential to increase inspection reliability, provide permanent inspection records which can be used to track part integrity during the life of the aircraft, and can establish a structured data base for statistical analysis of inspection results.

Under the sponsorship of the Air Force Wright Aeronautical Laboratory, General Dynamics' Fort Worth Division previously developed a five-axis laboratory prototype Computer-Automated Ultrasonic Inspection System (CAUIS) to inspect complex airframe forgings, Figure 1. This laboratory prototype CAUIS was developed under AFWAL contract number F33615-72-C-1728, and F33615-76-C-5104, and was successfully demonstrated on small forgings in a laboratory environment.

1.2 Objective

The system developed under these contracts clearly demonstrated the potential of computer-automated ultrasonic inspection. Near-net-shaped airframe forgings were inspected at scan speeds of more than 6-inches per second - a great improvement over previous manual or semi-automatic methods. Nevertheless, the system was a laboratory prototype. The benefits of a CAUIS had not yet been demonstrated in a production environment. For this reason, the Air Force Wright Aeronautical Laboratory awarded a follow-on contract to General Dynamics/Fort Worth Division. The goal of the contract was to demonstrate the benefits of a CAUIS configured for production inspection of large graphite/epoxy composite skins for the F-16 tail assembly.

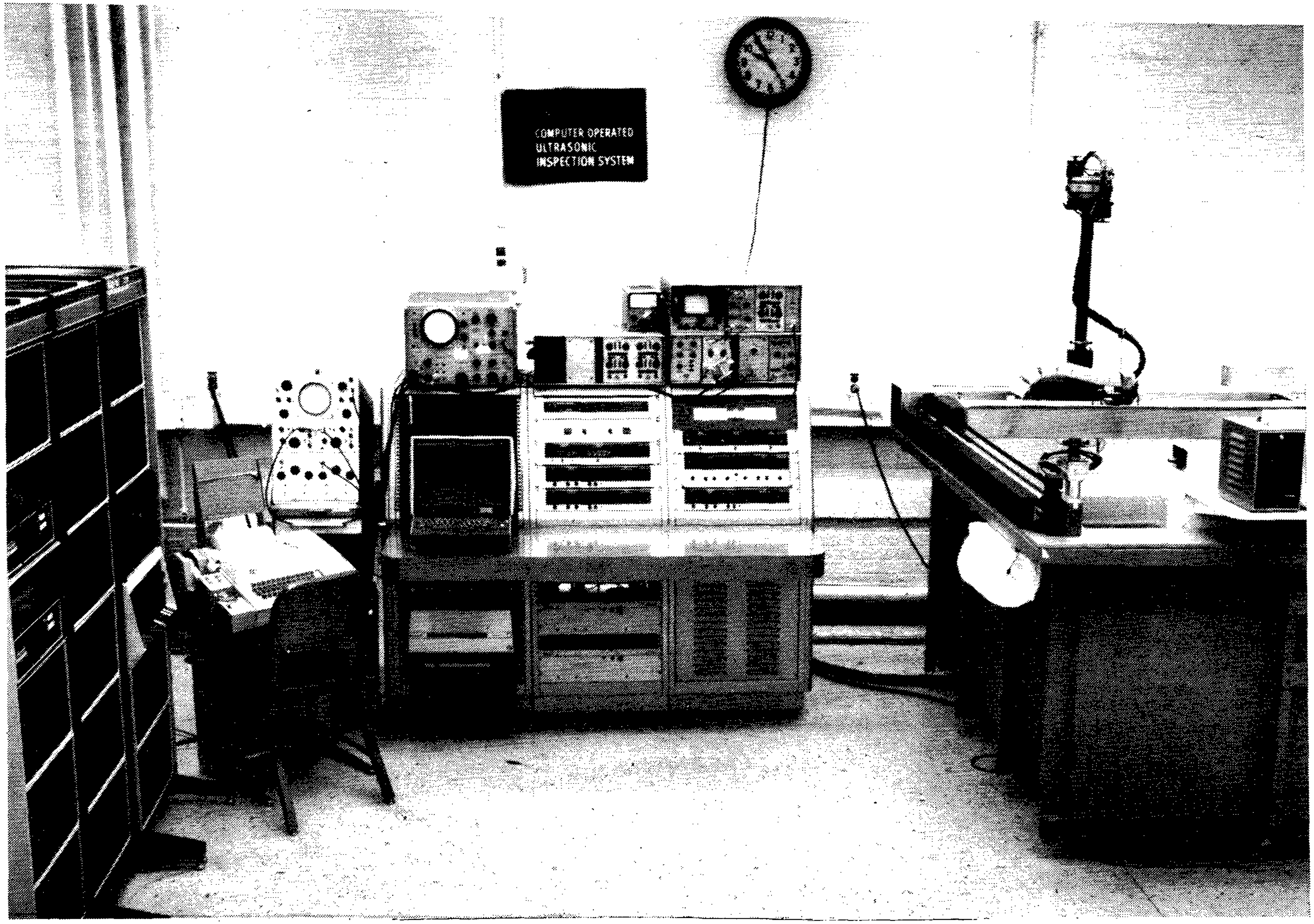


Figure 1 Original CAUIS Developed Under Earlier AFWAL Contract

The CAUIS was designed to utilize computer control of a scanning bridge, to computerize the data acquisition process, and to incorporate a multiplexed multiple element array transducer, all of which would provide for maximum scanning speed and system throughput.

The benefits to be demonstrated by the production CAUIS were (1) increased inspection rates, (2) decreased inspection costs, and (3) increased inspection reliability.

Finally, a Nondestructive Evaluation Terminal (NET) was to be established as a central data collection/management/evaluation system not only for this particular CAUIS, but for any additional computerized ultrasonic inspection systems implemented into F-16 production.

1.3 Scope

The original design requirements established in this contract called for the use of the major CAUIS components already developed under the earlier contracts for the laboratory prototype system. However, the requirements for a production CAUIS were quite different from those developed for the laboratory prototype. The size of the F-16 composite tail assembly skins to be inspected required the development of a very large immersion tank and bridge, and the availability of massive computer data storage.

An additional requirement was a large plotter to generate full size C-scans and a nine-track tape-drive for permanent storage of inspection results. Consequently, a complete set of new major subsystems for the CAUIS was procured and integrated into this program to meet the objectives of the contract. Figure 2 is a photograph of the production-configuration CAUIS developed by this contract.

The development of the production CAUIS included assembly and integration of the various subsystems (bridge, bridge drive electronics, bridge control microcomputer, ultrasonic unit, and master computer system), development of bridge control and data acquisition software, as well as integration of technologies developed during the CAUIS implementation program.

Figure 2 F-16 Production Computer-Automated Ultrasonic Inspection System

An ultrasonic transmitting/receiving linear array transducer operating in a time-multiplexed mode was also adapted and implemented on the CAUIS. The multiplexed linear array consists of the following system elements:

- o Ultrasonic multiple array transducer
- o Multiplexer/demultiplexer hardware required to switch the transmitted and received ultrasonic signals between transducer elements
- o Specialized digital interface required to control the multiplexer/demultiplexer hardware.

A Nondestructive Evaluation Terminal was established to serve as a centralized data collection and management system for the CAUIS, Figure 3. The NET will ultimately be linked to all computer-automated ultrasonic inspection systems in use on F-16 production. Figure 4 illustrates the network currently implemented at Air Force Plant No. 4 in Fort Worth, as well as future planned developments.

The NET has been interfaced with each Computer-Automated Inspection System in the production network by a high-speed data link. This NET/CAUIS linkup facilitates automatic data collection and archival of all inspection results. The NET system provides sophisticated flaw evaluation capabilities. Also, as the NET collects data from the CAUIS, it provides periodic quality assurance management reports and statistical analyses which can detect and even anticipate problem trends in the manufacturing process.

As of the publication date of this final report, the NET has been successfully linked to the two computer-automated ultrasonic inspection systems implemented in the factory -- the CAUIS established by this contract, and a computer-automated "squirter" system manufactured by Automation Industries, Inc. of Chatsworth, California, Figure 5. The AI inspection system, while not part of this contract, was developed simultaneously. A future development will involve computerization and NET linking of a second "squirter" system in current use in the factory, Figure 6.

Figure 3 Nondestructive Evaluation Terminal for Central Data Collection and Management

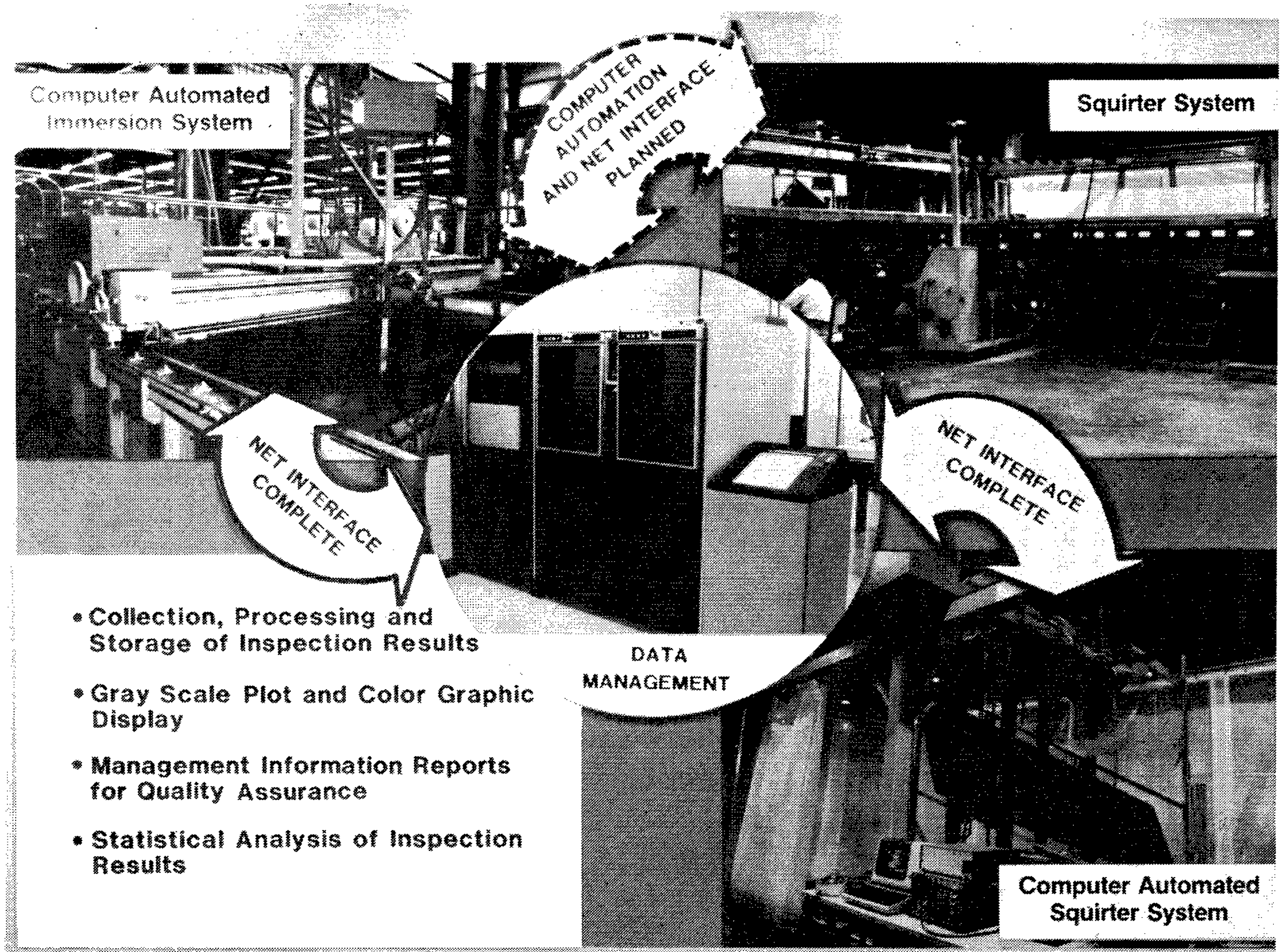


Figure 4 The NET Has Been Successfully Linked to Two Computer-Automated Inspection Systems

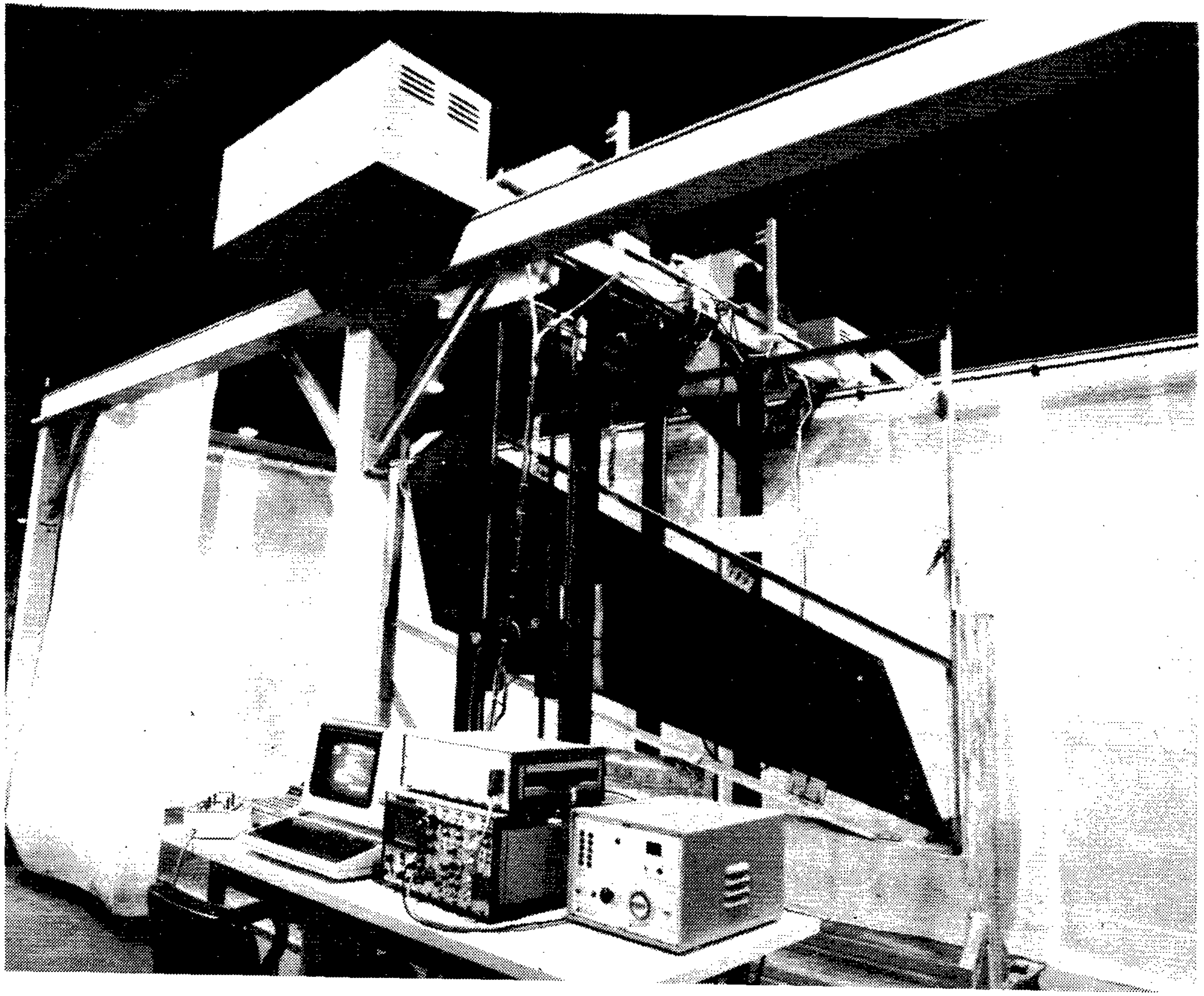


Figure 5 Automation Industries "Squirter" Ultrasonic Inspection System Is Computer-Automated

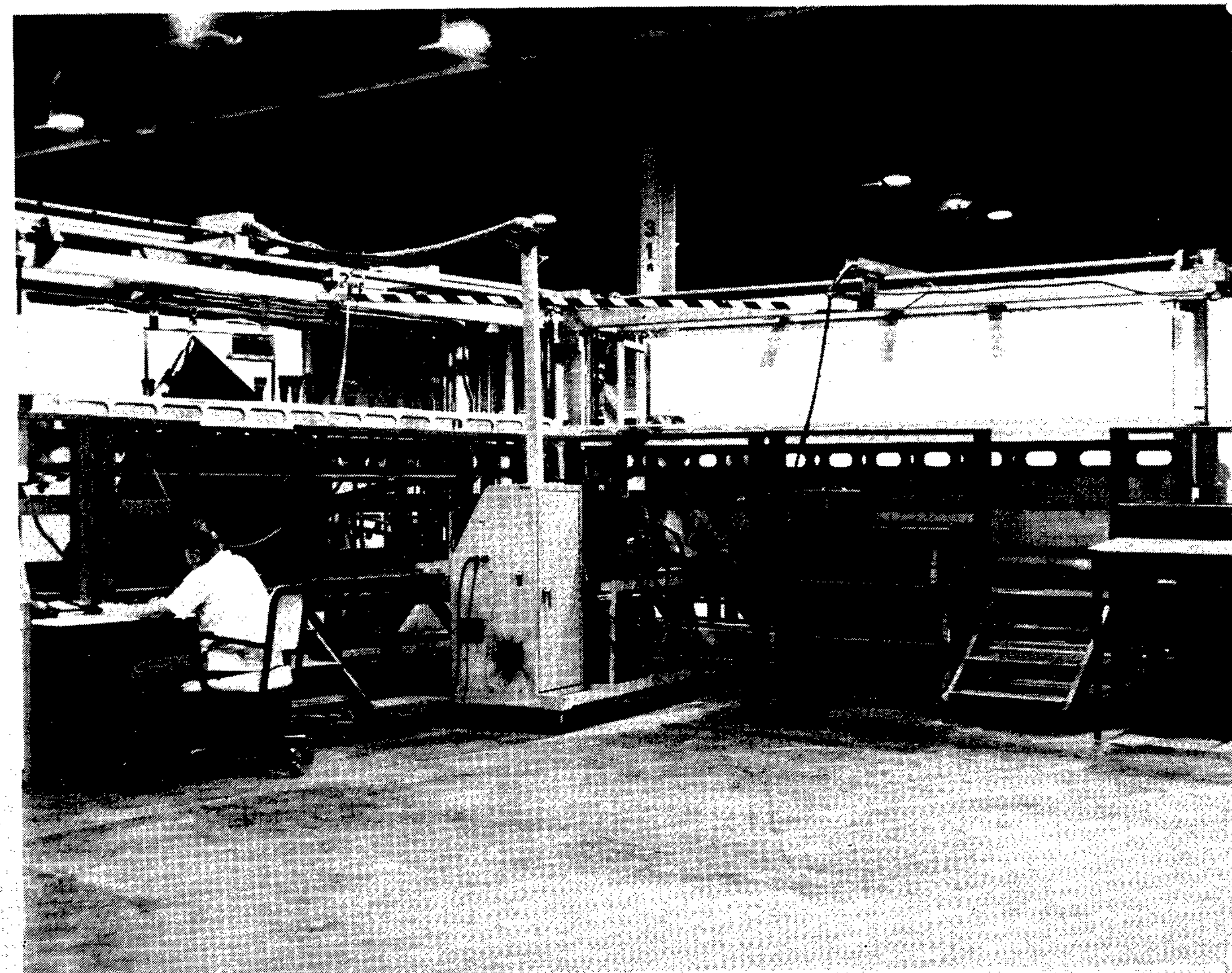


Figure 6 Tektran "Squirter" System Will Be Computer Automated and Linked to the NET

2.0 PRODUCTION CAUIS SYSTEM DESIGN

The Computer-Automated Ultrasonic Inspection System was designed and implemented at General Dynamics/Fort Worth Division for production inspection of large F-16 composite tail assembly skins. These graphite/epoxy composite parts include the skins of the F-16 horizontal and vertical stabilizers, rudders, and stabilizer leading edges, Figure 7. These current production laminates are essentially flat, or have minimal contour. However, F-16 derivative aircraft as well as the next generation of fighter aircraft will include considerably larger proportions of advanced fiber composites, Figure 8. These larger laminates will make up much more highly complex airfoil and fuselage structures than those currently being produced, and will require the development of equally complex inspection technologies to keep pace with advances in production. While the CAUIS was designed to inspect the relatively simple laminates of the current F-16, provisions were incorporated into the CAUIS design to allow for future expansion of the system to include inspection of larger and more complicated parts.

The production-configured Computer-Automated Ultrasonic Inspection System is more advanced than past laboratory-type systems. It operates on a 12-foot by 30-foot (by 6-foot deep) immersion tank. A sturdy bridge, search tube, and manipulator are included. The bridge is controlled by a special-purpose microprocessor subsystem. This allows execution of complex scan patterns without attention by the master data acquisition computer, thus freeing the master computer to perform the more critical inspection result acquisition and management tasks, Figure 9. This feature was critical to the success of the time-multiplexed array development. The system includes a PDP-11/34 master computer for high reliability; 35 Megabytes of disk storage capacity and a high-speed (125 inch per second) nine-track tape drive to handle the production data rates and volume; and a 6-foot wide Versatec plotter to provide a full-size C-scan hard copy of the inspection results. A direct-memory access port between the computer and the ultrasonic unit is incorporated to manage the high data rates from the time-multiplexed array. A very high speed data-link transmits the inspection results to the Nondestructive Evaluation Terminal data management system. A DEC terminal serves as the inspector's control console. The ultrasonic unit is an Automation Industries S-80 complete with a digital interface. This extensive use of production, off-the-shelf subassemblies provides high reliability and simplifies system maintenance.

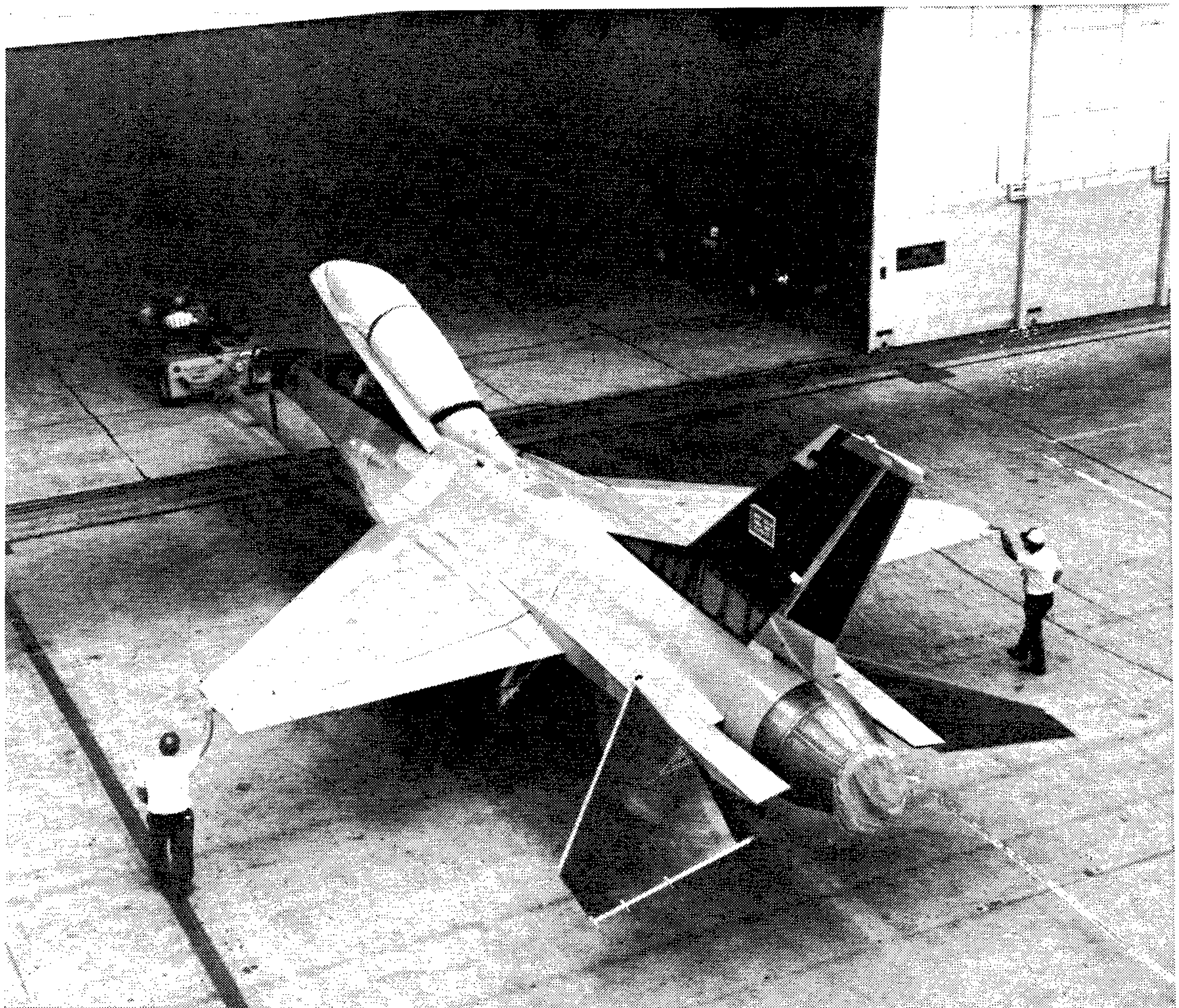


Figure 7 F-16 Empennage Showing Graphite/Epoxy Composite Skins

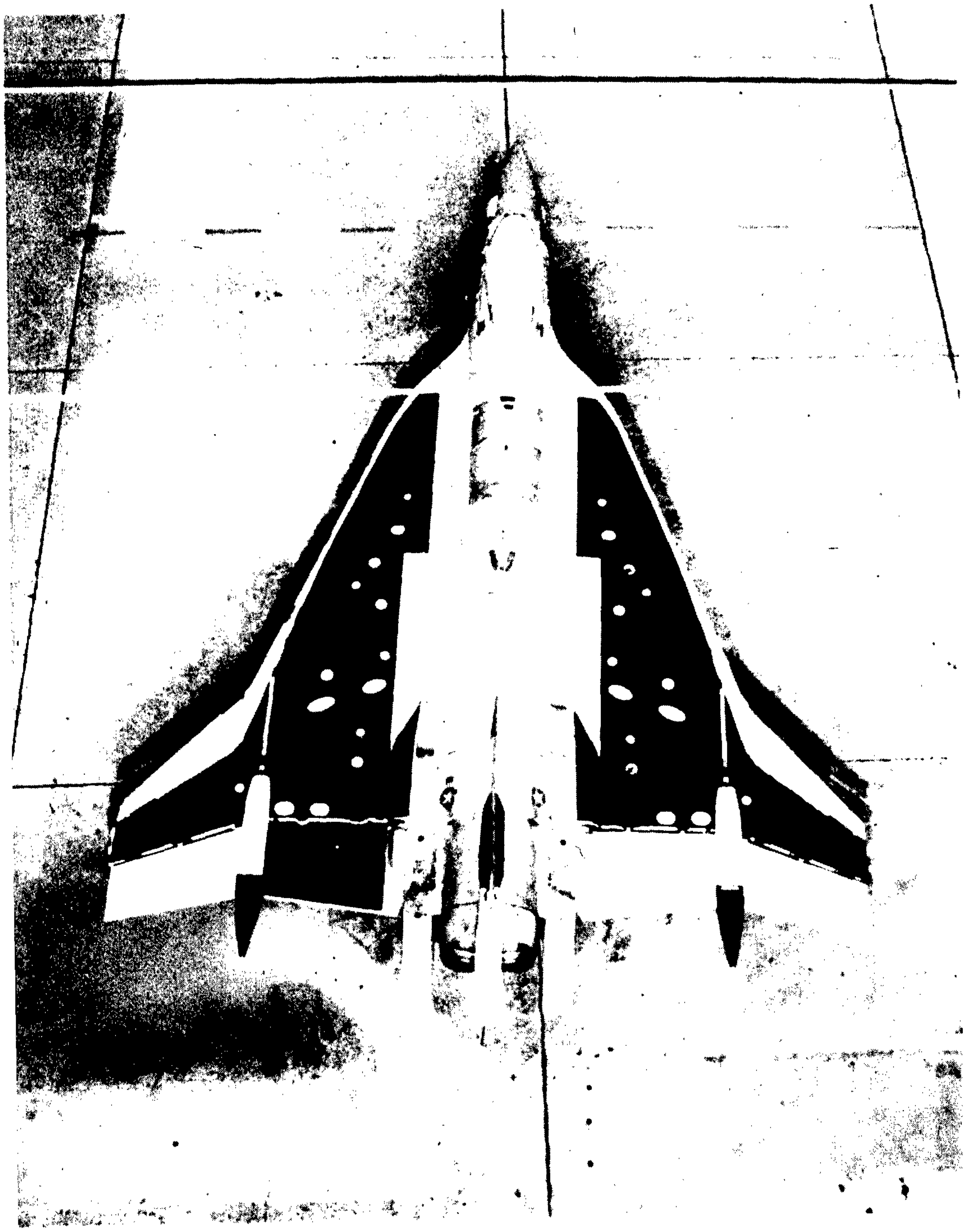


Figure 8 Next Generation Fighters Will Incorporate Larger and More Complex Composite Laminates

Figure 9 The Bridge Microprocessor Frees the Master Computer for Data Acquisition and Management Tasks

2.1 System Overview

The basic CAUIS station operates in a reflector plate mode by bouncing ultrasonic energy off an aluminum plate. This mode is presently the best immersion technique available for inspecting graphite-epoxy composite skin panels. However, the system was designed to allow operation in a conventional pulse-echo mode (single transducer only). This capability is required should other parts or raw stock require inspection, or in the event of future advances in ultrasonic signal processing which would allow use of the pulse-echo mode with the composite skin panels. Figure 10 illustrates the difference between reflector plate and pulse-echo inspection techniques.

Ease of transition from a single transducer mode of operation to the time-multiplexed array mode was a primary consideration during system design. The software for the basic CAUIS is totally insensitive to the mode of operation in use; i.e., precisely the same software is used for single-channel and time-multiplexed modes of operation. The hardware modifications for mode changes are restricted to interchanging the search tube containing the array head and multiplexer with a search tube which contains a conventional transducer, rotate-and-tilt manipulator and drive, and a conventional preamp. The manipulator assembly is not required for array operation, since the very nature of the array geometry makes it unsuitable for inspecting highly nonplanar geometry parts. Electrical connections are made through an RF coaxial cable with a quick disconnect BNC connector and a single connector carrying logic signals and power.

An inspection is initiated when the inspector requests a specific part number inspection parameter data set. The master computer retrieves inspection parameters from the system disk. Setup commands for the ultrasonic unit are issued. Certain information is requested from the inspector (e.g., part serial number, inspector identification, Inspection Reference Panel number, and other required inspection parameters). The inspector then loads the part in the tank into its proper location and notifies the computer when the part is ready for inspection. Information describing the first scan line of the scan program is passed to the microprocessor bridge controller. The first scan line of the scan pattern begins execution, and the master computer then waits for data that it can act upon.

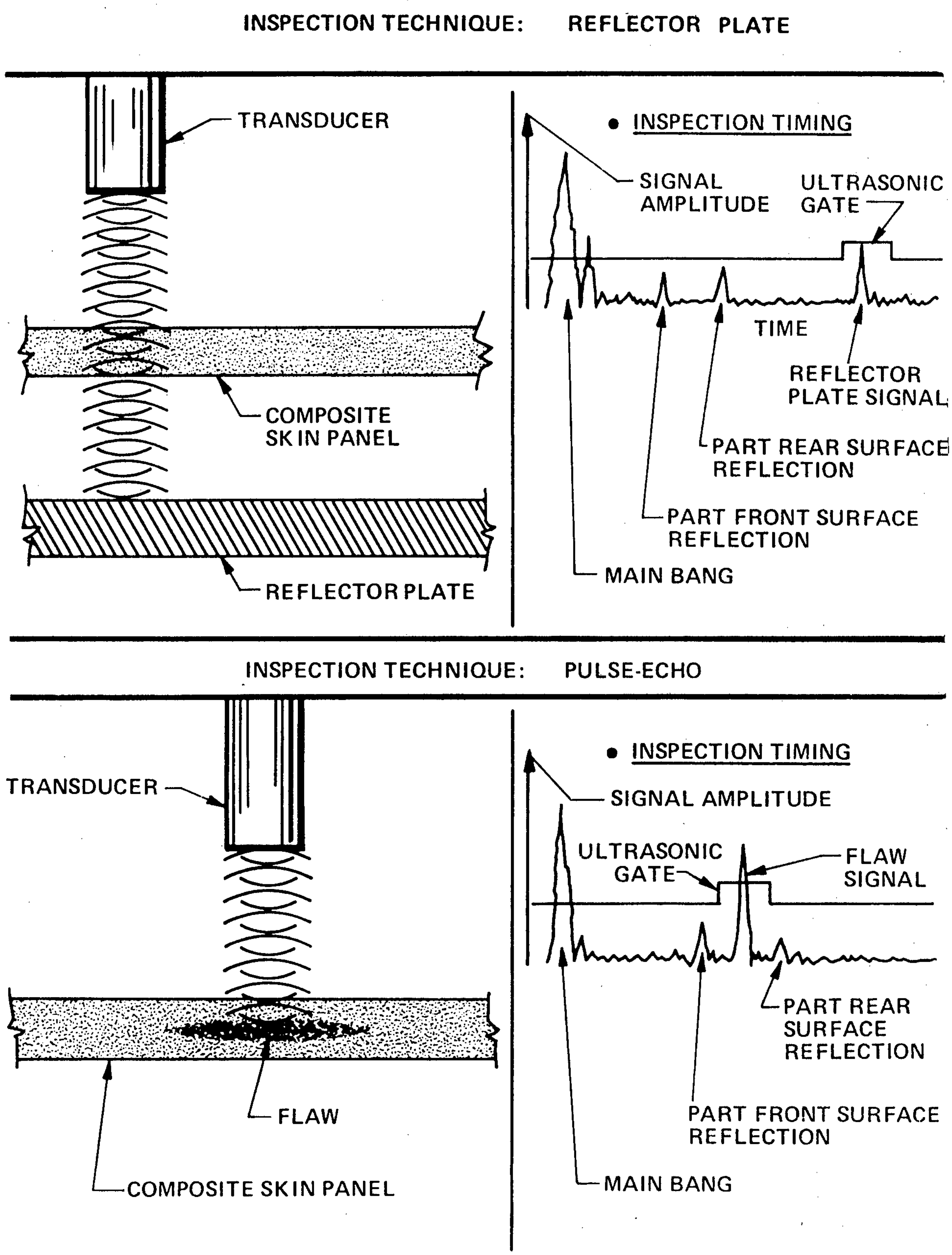


Figure 10 Comparison of Reflector Plate and Pulse-Echo Inspection Technique

The ultrasonics and data acquisition system are controlled by bridge motion. A trigger pulse is generated whenever the bridge scanner moves .080-inch (the selected inspection lattice spacing). This trigger pulse initiates a data acquisition system cycle. Each data acquisition cycle fires the ultrasonic unit, captures, amplifies, and gates the received signal, digitizes the received signal, and transfers the digitized values to hardware circuits which eliminate redundant data (described below). When operating in the time-multiplexed mode, the trigger pulse initiates action by the array controller, which in turn causes a series of data acquisition cycles, one for each transducer channel. Locking the data acquisition system timing to bridge movement ensures that data will be taken at regular spatial lattice points. This allows maximum independence of the master computer and the bridge controller. It also automatically compensates for speed ramp up/ramp down required of the scan axis.

The large size of the F-16 composite skin panels requires that special techniques be employed to eliminate redundant data to the maximum extent possible. In addition, the complexity of the panels (constantly tapered thickness, variability of acoustic properties, rough surface), combined with a requirement that a common data structure be used for all present and future CAUIS stations, requires a highly flexible data structure.

To provide maximum flexibility and growth, both the ultrasonic signal amplitude and depth information are acquired. Amplitude information is recorded on a logarithmic scale with 1 dB as a quantization interval. This provides capability for acquiring signals with extremely high dynamic range. Signal variations of less that 1 dB are generally not significant. Depth information is recorded on a linear scale using an adjustable quantization interval.

To eliminate redundant data, all contiguous lattice points oriented along the scan axis which have the same value of amplitude and depth are grouped together and characterized as a line or "vector" of data with a single specified amplitude, depth, and length. The elimination of redundant data is performed in the ultrasonic unit digital interface hardware before the inspection results enter the computer. The same operation and interface hardware are used to accomplish this function for both the single channel and time-multiplexed modes of operation. The digital interface

hardware determines if the multiplexer unit is electrically connected and operates accordingly. Single channel operation of the digital interface is accomplished by using only one channel of the time-multiplexed interface hardware.

Each data acquisition system cycle causes the present amplitude and depth data available from the ultrasonic unit to be compared to the last remembered values (for the currently addressed channel, if time-multiplexing). If values are the same, the length count is incremented and no data is shipped to the computer. If the values are different, the last remembered values are sent to the computer Direct Memory Access port, followed immediately by the length and channel number data. The last remembered values are then updated to the values presently available from the ultrasonic unit, and the length-counter is reset to zero. This is the beginning of a new line, or "vector" of data. Separate last-remembered values of amplitude and depth and a separate length-counter are maintained for each of the time-multiplexed channels. Single channel operation is accomplished by setting the channel number bus lines to a specified value that is not allowed to change.

An interface with the DMA port allows asynchronous entry of data word pairs. This is a simple bus multiplexer with timing and "handshake" control logic to provide full asynchronous operation at the DMA port.

During data acquisition, a pair of circular buffers are maintained. At any given time, one buffer is dedicated to accepting data from the ultrasonic unit, and one buffer is dedicated to recording data on disk. At the completion of a scan line, the bridge control microprocessor issues a "flush vector" command which causes all vectors being held in the data reduction electronics to be transferred to the data acquisition computer. The bridge control processor then checks status of the data reduction electronics and transmits it to the master data acquisition computer. This signals the end of a scan line to the master computer, which then retrieves data for the required index move and the next scan line. This information is transmitted to the bridge controller, and the process is then repeated until the inspection is completed.

Upon completion of an inspection, the bridge moves to the home position so the operator can remove the part from the tank. The Master Menu (See section 3.4.1.1) is then displayed on the system control console. The operator may elect to plot the inspection results,

transmit them to the NET system, inspect a new part, or any of the other functions normally available to the operator.

The following sections describe the system hardware and software elements which comprise the CAUIS production system.

2.2 CAUIS Hardware

The block diagram in Figure 11 depicts the major hardware components of the CAUIS. The total system consists of the following subsystems:

(1) Immersion Tank

(2) Bridge/Carriage Assembly

(3) Bridge Control Microcomputer

(4) PDP 11/34 Control and Data Acquisition System

(5) Ultrasonics

(6) Ultrasonic Interface and Data Reduction Electronics (SIC)

(7) Array Transducer

(8) Array Multiplexer

The following paragraphs describe these subsystems in detail.

2.2.1 Immersion Tank

The CAUIS development program utilized an existing immersion tank that had been installed a number of years ago for receiving inspection of aluminum plate, Figure 12. The CAUIS immersion tank measures 12 feet by 30 feet by 6 feet deep. The tank is equipped with a large drain, overflow skimmer, and a pump and filter system. Screw-and-bracket assemblies are fastened to the tank interior side walls. These brackets support a 3/4-inch thick aluminum reflector plate, and allow the plate to be leveled, as well as raised and lowered as required.

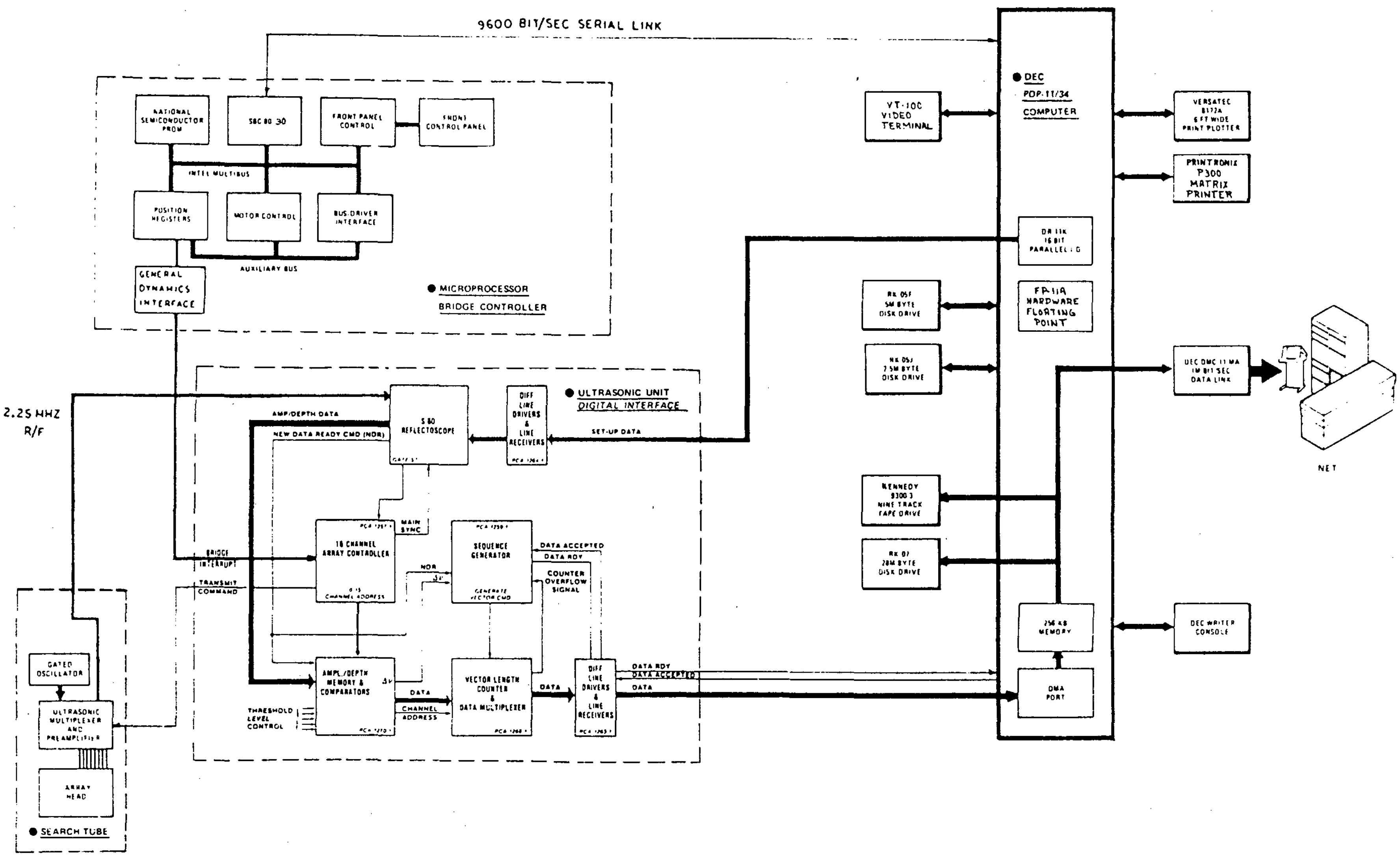


Figure 11 CAUIS Block Diagram From an Equipment Perspective

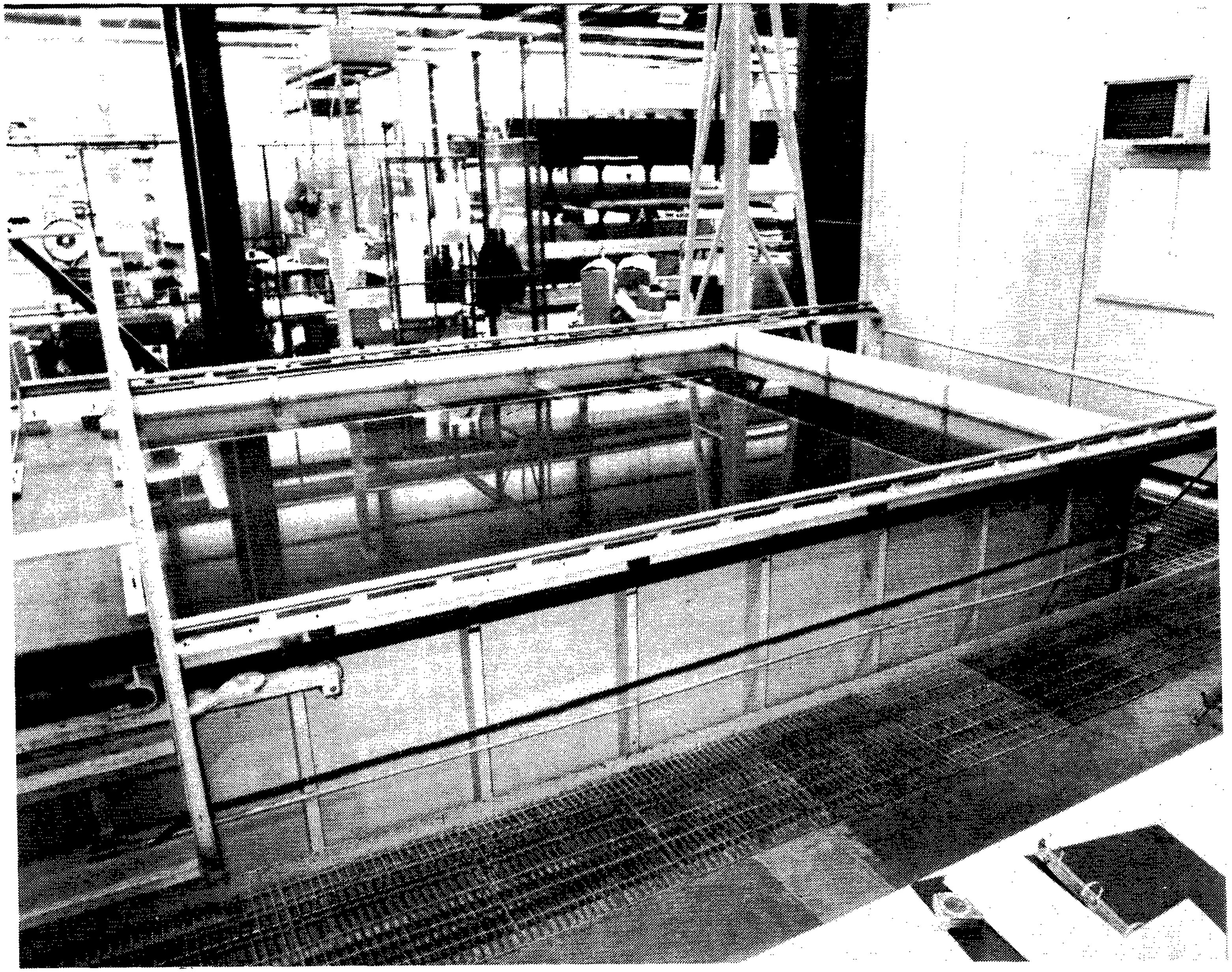


Figure 12 The Immersion Tank Was Originally Used for Receiving Inspection of Aluminum Plate

2.2.2 Bridge/Carriage Assembly

The immersion tank is fitted with roundways that support the bridge/carriage assembly. The bridge spans the width of the tank and the carriage assembly extends across the bridge. The bridge /carriage assembly is computer controlled and has motorized X, Y, and Z axes. Scanning the part is a Y-axis (width of tank) function, indexing is performed in the X-axis (long axis of tank), and the Z-axis (vertical) controls the distance between the transducer and the composite part being scanned, Figure 13. The X and Y axes are driven by DC servo motors and SCR controllers. The Z axis is driven by a stepper motor. The X and Y axis are fitted with both brakes and clutches, but the Z axis requires only a brake. Limit switches control the maximum travel distance of all three axes and shut down the drive motors when actuated. Each axis also has an encoder to provide position information to the bridge control microprocessor.

2.2.3 Bridge Control Microcomputer

The bridge control microcomputer coordinates and controls the CAUIS X,Y, and Z axes through the bridge motor drive system. Figure 14 is a photograph of the bridge control microcomputer. The bridge can be moved in three modes: manual, local, and computer. The manual mode is activated via joystick control and cannot be used in the actual ultrasonic scanning task. The local mode allows the operator to set up and execute specific rectangular scan patterns by keying in the scan parameters from the front panel. The computer mode allows the bridge control microcomputer to accept motion commands from the PDP-11/34 master control and data acquisition computer via RS 232 serial communication link. The bridge controller also provides initialization, control, and status monitoring of the ultrasonic data reduction electronics through 7 discrete I/O lines.

The bridge controller is composed of seven discreet circuit cards as shown in the block diagram in Figure 15. The individual circuit cards are interconnected through the Multibus card cage. The CPU card is an Intel 80/30 single board computer with 16k bytes of dynamic RAM, two serial I/O ports, and 24 discrete I/O lines. The 16k byte EPROM memory card contains the bridge controller operating system and software. The front panel control card interfaces all front panel switches, lights, numeric displays, and local

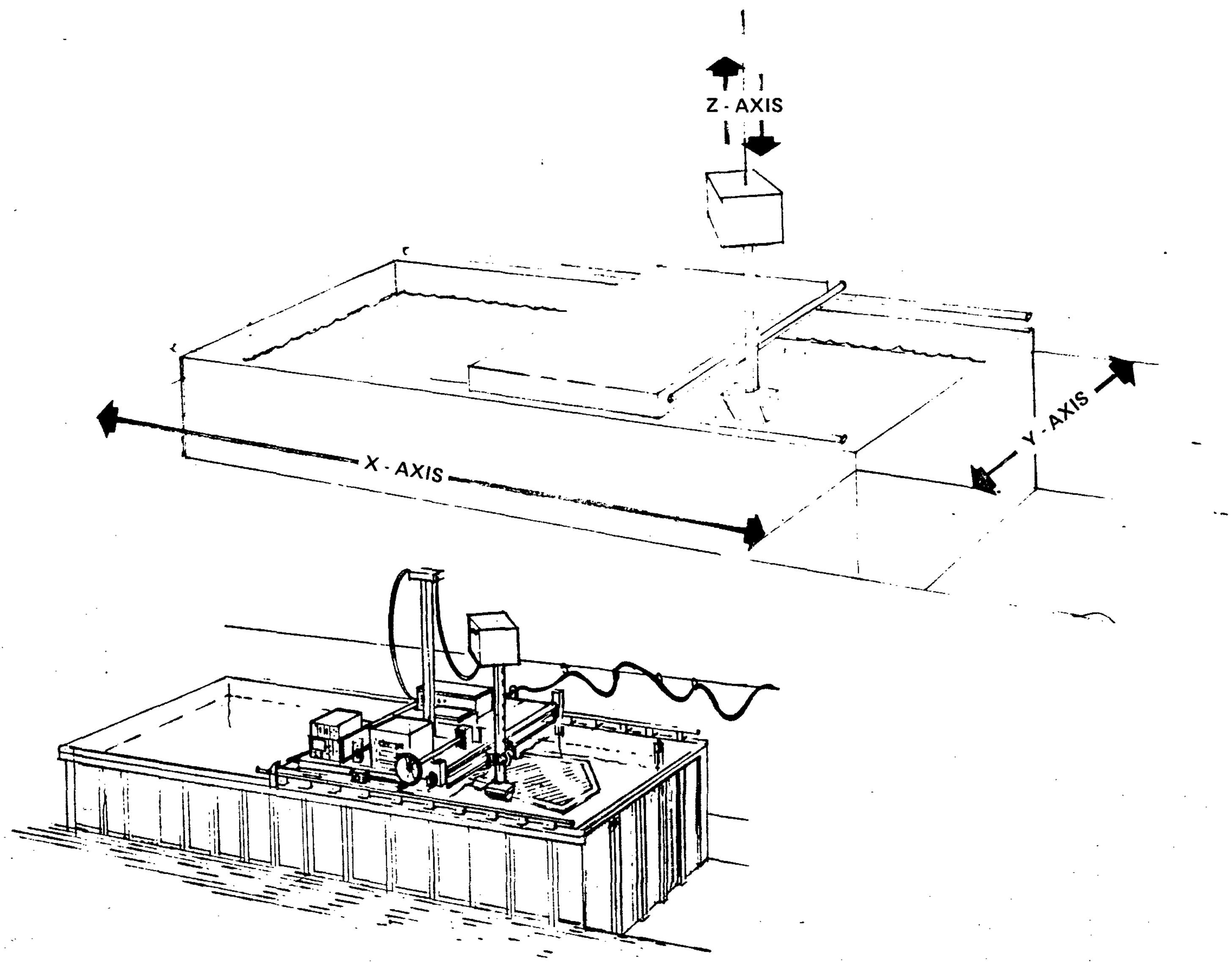


Figure 13 Immersion System X, Y, and Z Axes

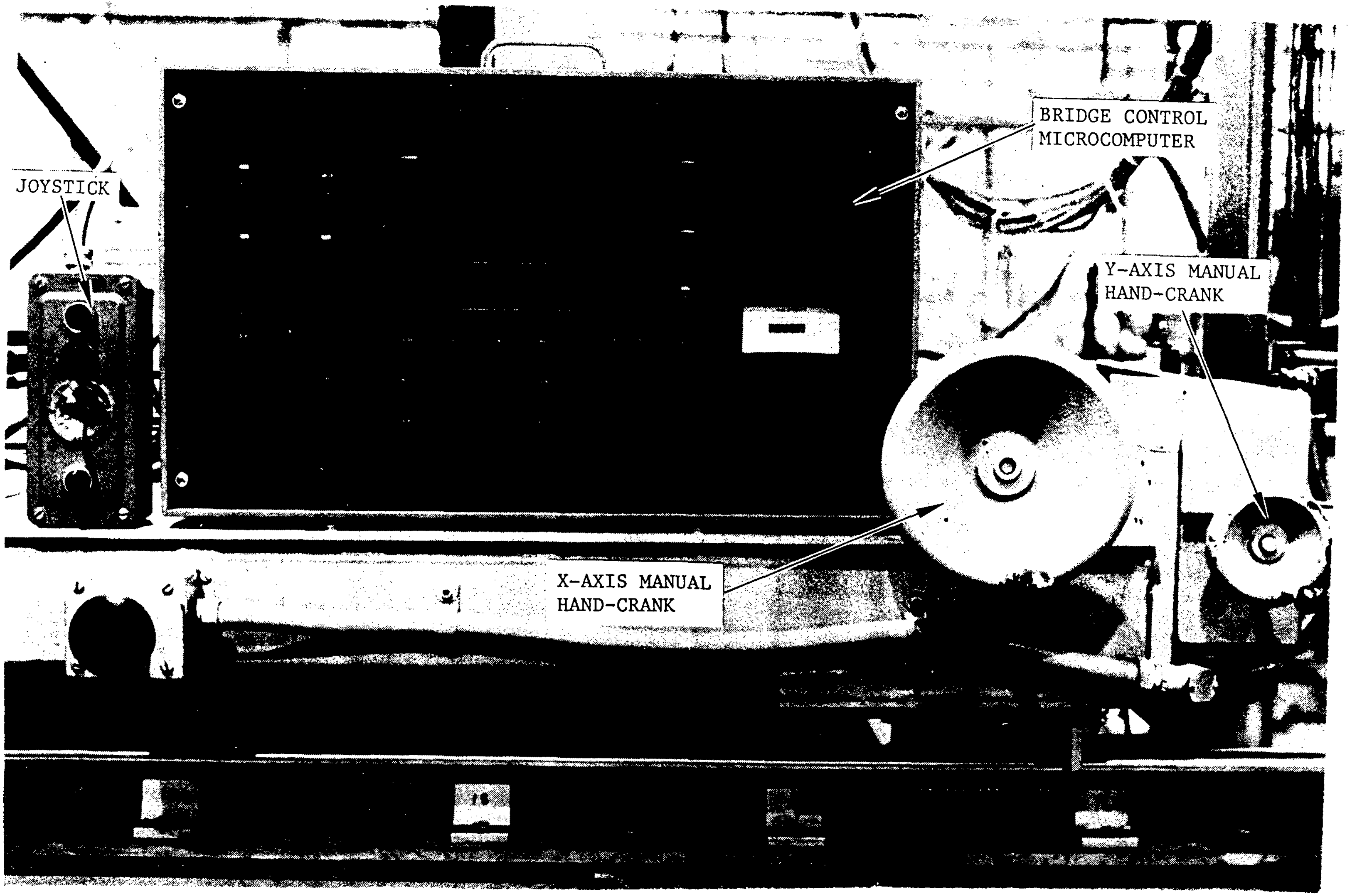


Figure 14 Bridge Control Microcomputer

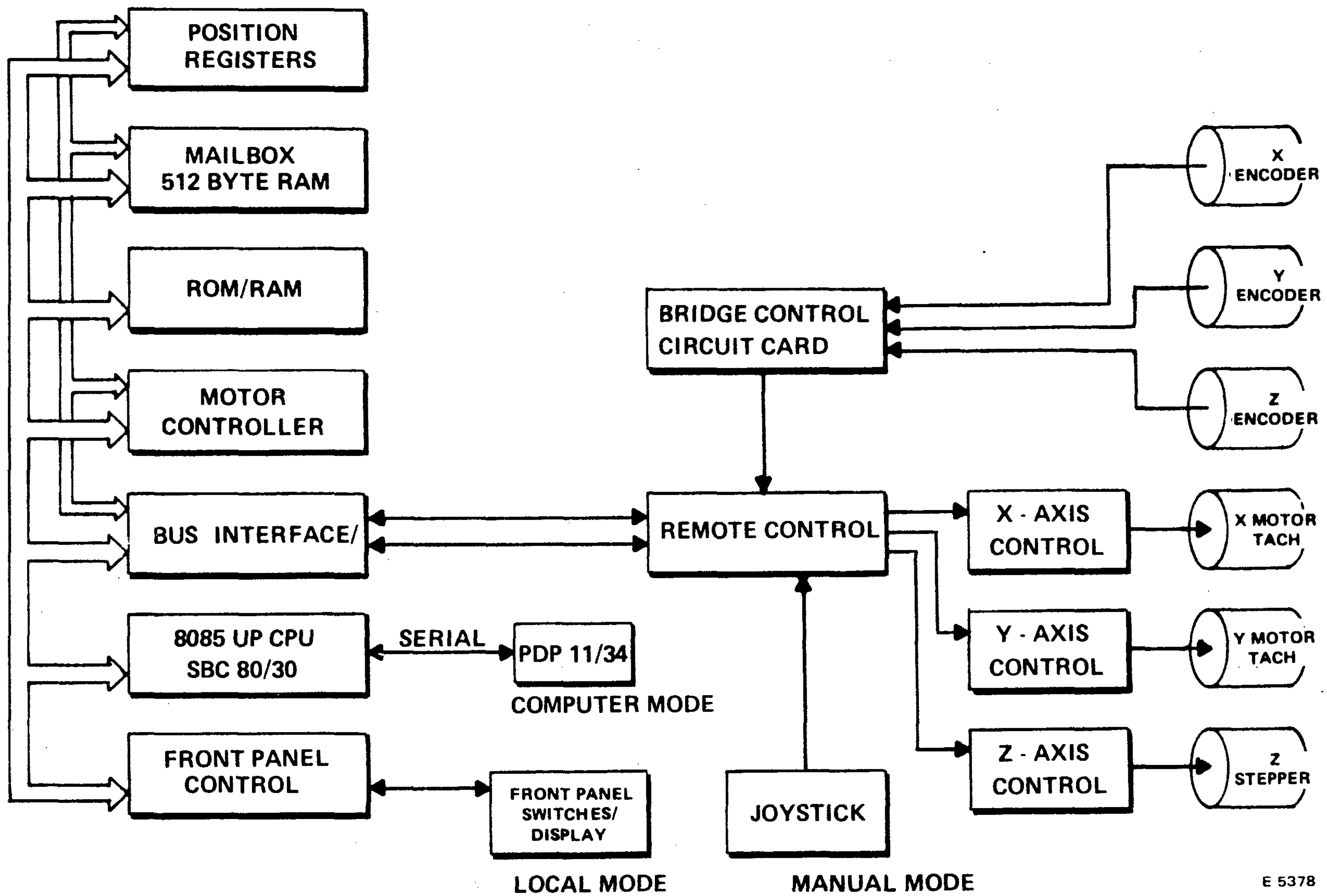


Figure 15 Bridge Controller Circuit Cards

mode functions to the microcomputer. The position register card maintains the current bridge position coordinates at all times. The "mailbox" card is used to retain the currently active scan commands. The motor control card produces the motor drive signals and the I/O driver card interfaces these signals to the motor drive electronics. An eighth circuit card contains line drivers and line receivers for the RS232 serial data link and the discrete I/O lines that interface to the data reduction electronics.

The interior of the bridge control microcomputer is shown in Figure 16. Large-capacity power supplies were incorporated to provide for future expansion of bridge controller circuitry. In accord with the growth-oriented design philosophy, an additional four-element card cage was connected to the subsystem data bus. Standard connectors are used to interface with the remainder of the immersion system, allowing quick disconnect of the bridge controller from the remainder of the system for maintenance and repair procedures. Two fans are provided at the rear of the cabinet to assure adequate cooling and high reliability. The modular design assures easy trouble-shooting and low mean time to repair.

2.2.4 Control and Data Acquisition Computer System

The CAUIS control and data acquisition system consists of a Digital Equipment Corporation PDP-11/34 minicomputer with 256k bytes of internal memory and a hardware floating point processor. Figure 17 is a photograph of the system hardware. A VT-100 terminal serves as the CAUIS station operator's control console. Two disk systems are included; a small RK05F/J which contains the operating system and CAUIS software, and an RK07 28M byte disk which is used to store inspection results. A communications link allows for transmission of inspection results to the Nondestructive Evaluation Terminal data management system which is described elsewhere in this report. A nine-track magnetic tape drive provides longer term storage of inspection results as well as an alternate method for transporting inspection results to the NET. A large six-foot Versetec plotter and a smaller Printronix graphics printer provide for display of the inspection results.

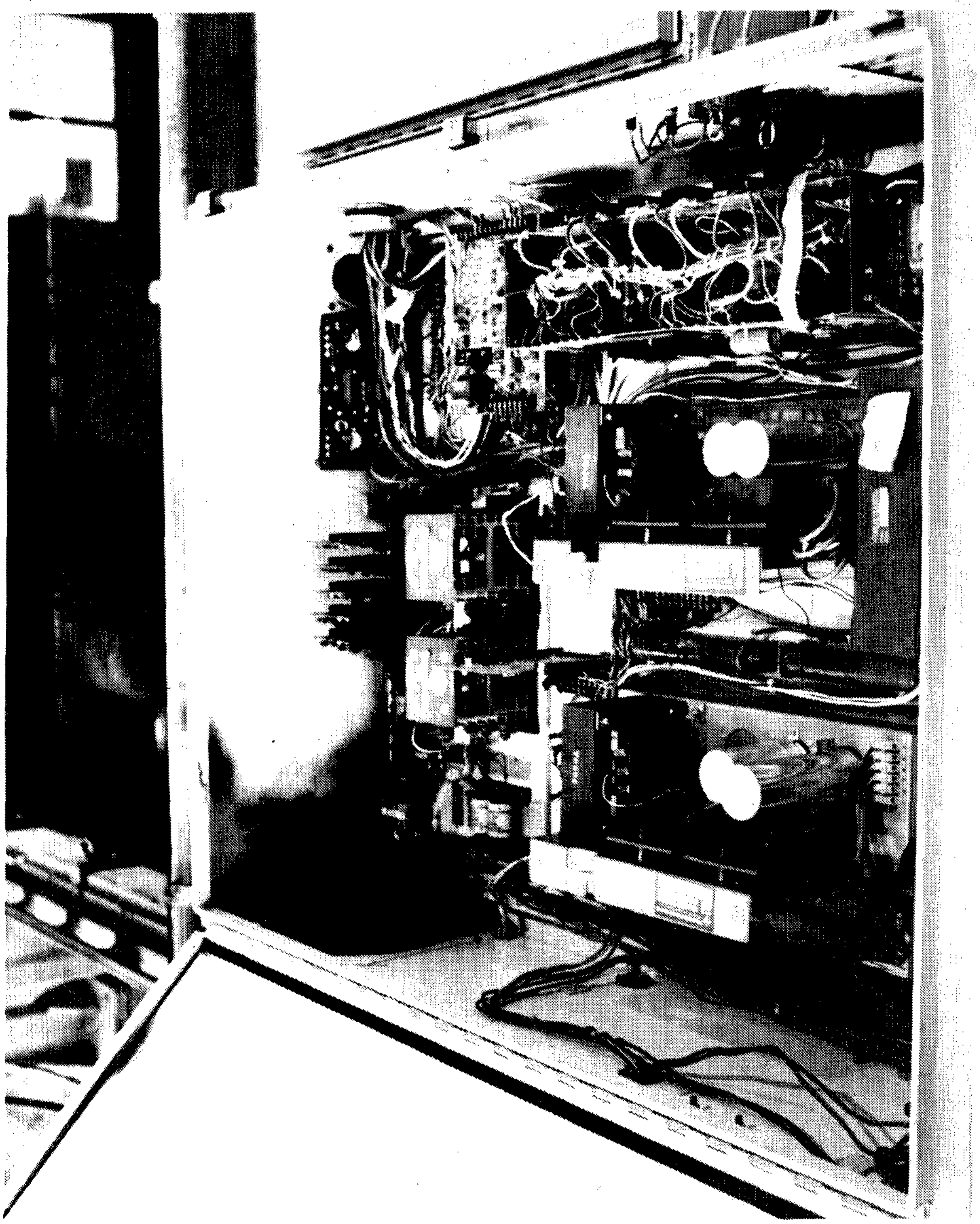


Figure 16 Interior of Bridge Control Microcomputer

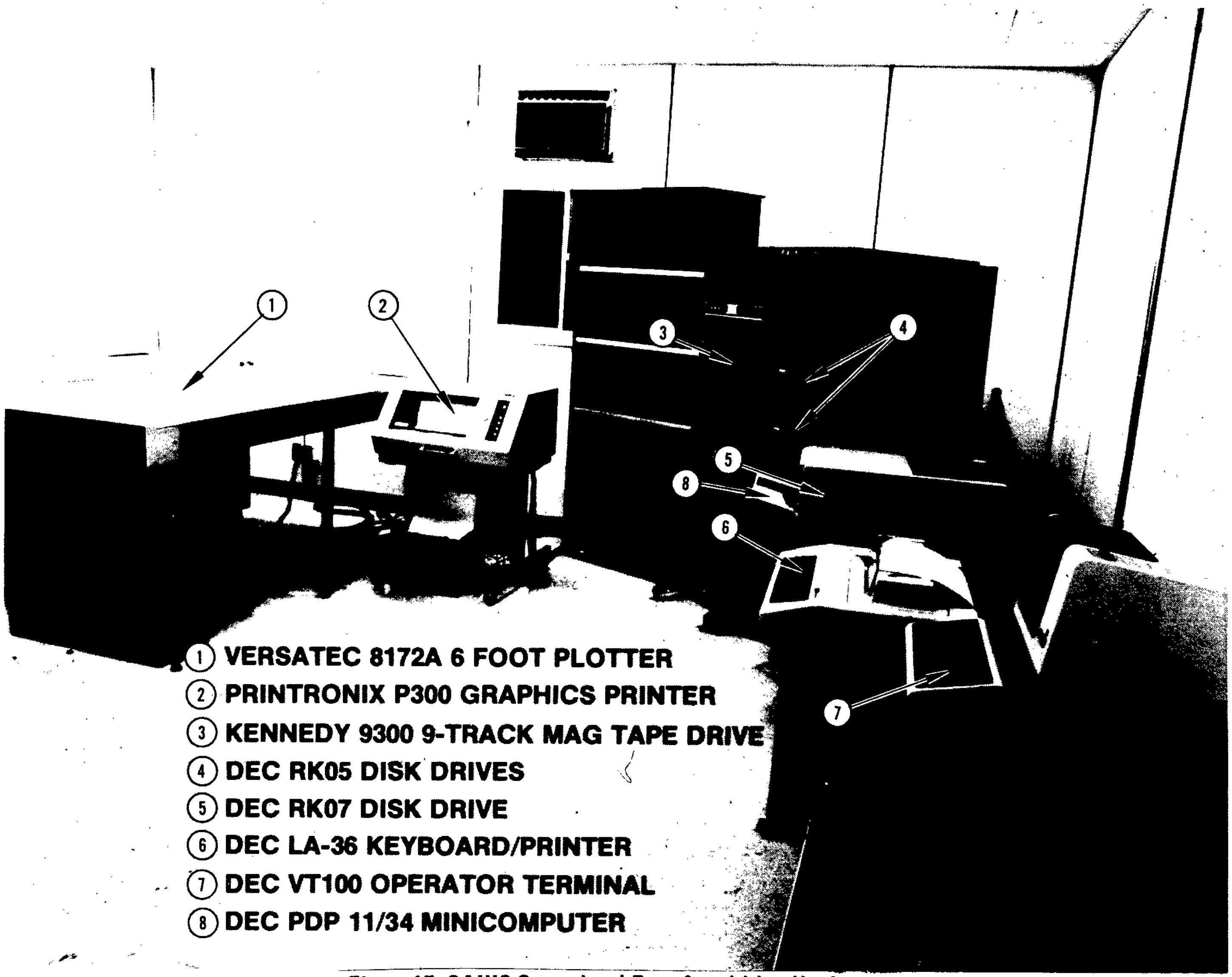


Figure 17 CAUIS Control and Data Acquisition Hardware

The system also includes a direct memory access (DMA) port and other hardware to interface directly with the ultrasonic unit, the data reduction electronics, and the bridge control microcomputer. The system utilizes the DEC RSX-11M Version 3.2 operating system and the application software is written in Fortran IV.

2.2.5 Ultrasonic Unit

Ultrasonic instrumentation selection for the CAUIS was based on two primary requirements: 1) digital interfacing capability, and 2) capability for a through-transmission as well as pulse-echo inspection modes of operation. A survey of available off-the-shelf ultrasonic inspection equipment was conducted. The survey concluded that the most suitable instrument for the production CAUIS station was the Automation Industries S-80 Reflectoscope.

Remote control is a valuable tool in the automatic inspection of complex geometries and high speed testing of variable shapes, and in situations where defect gating may be too involved for reliable operator adjustment. The S-80 permits digital remote control under these circumstances. The S-80 also permits customized digital interfacing through a System Interface Cabinet (also supplied by Automation Industries). In combination, the S-80 and the SIC form an ultrasonic inspection instrument with digital data acquisition capabilities and a computer-controlled flaw gate. The S-80 Reflectoscope was selected for the Computer Automated Ultrasonic Inspection System because of its modular design and computer interface capability.

The S-80 provides a Cathode Ray Tube (CRT) for display of the gate and flaw signals, a chassis for mounting and electrical interconnection of the other ultrasonic unit modules, and numerous manual controls for ultrasonic component adjustment and setup. Other modules selected for the production CAUIS include a PR-2 pulser/receiver module, a DAG-1 distance amplitude gate/distance-amplitude compensation module, and a programmable GT-3 remote control gate module. Figure 18 is a photograph of the S-80 unit and its System Interface Cabinet.

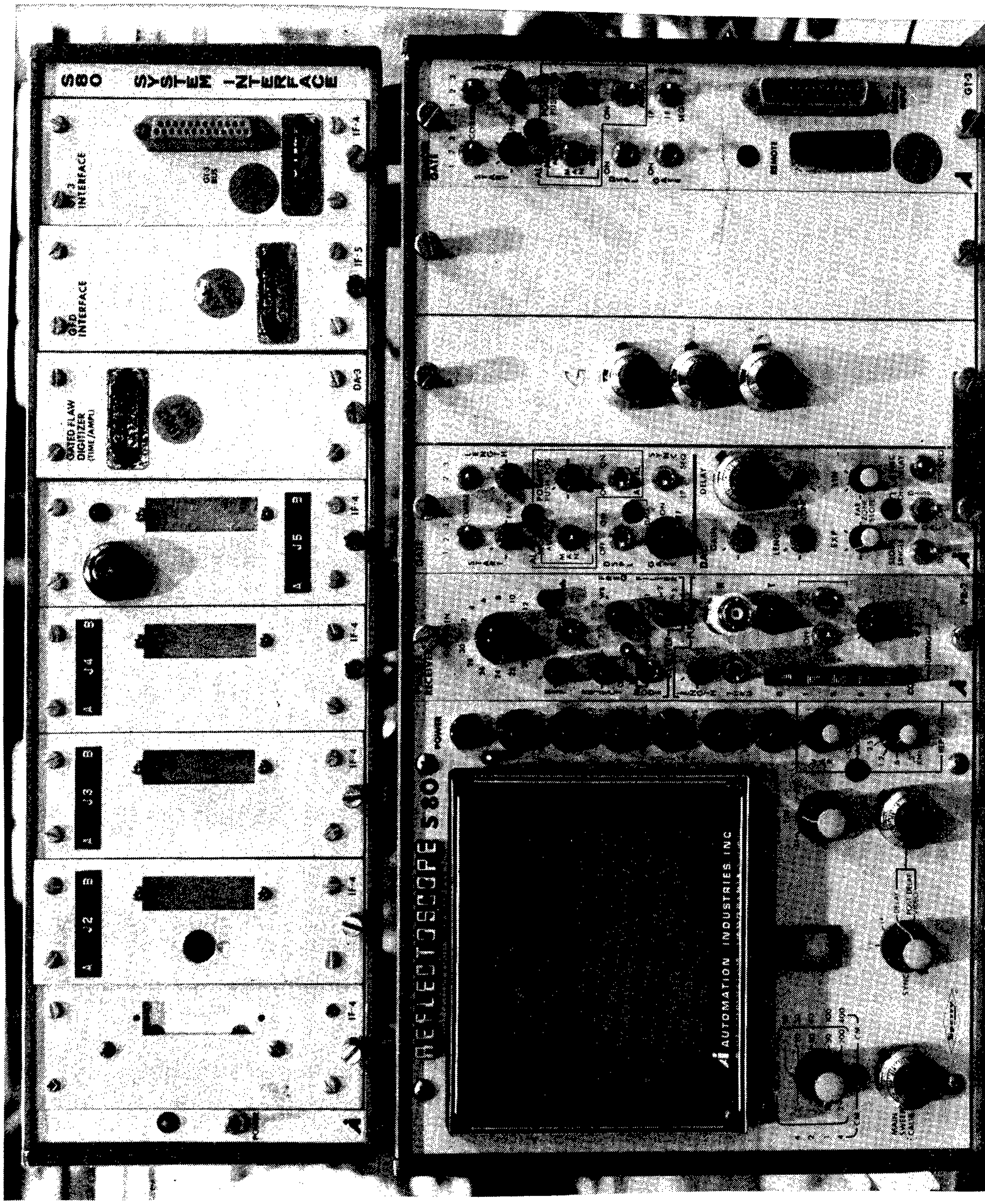


Figure 18 S-80 Reflectoscope and System Interface

The PR-2 unit combines a pulser module with a high-gain narrow-band tuned receiver covering the standard ultrasonic frequencies in the range of 0.4 - 10 Megahertz. The receiver section also has a moderately wide band response capability centered at 5 megahertz. The pulser section of this module is not used when the production CAUIS is operating in the time-multiplexed array mode. A gated transmitter within the multiplexer unit is used to excite the transducer array and will be discussed in the array multiplexer section of this report. This pulser section would be required, however, for a pulse-echo inspection technique.

The DAG-1 module combines a distance amplitude gate and a distance amplitude compensation function to provide a maximum peak compensation of 35dB when used in the receiver DAC mode and 20dB when used in the DAG mode. The unit's front panel standard potentiometers which control the shape of the DAC/DAG characteristic were removed and replaced by ten turn potentiometers which were installed on an adjacent blind panel. This significantly improves inspection repeatability and the ease of setup on the wide dynamic range signals and steep DAC slopes required for automated inspection of F-16 vertical stabilizer composite laminates.

The GT-3 remote control gate module provides the gate functions for the S-80. It can be controlled manually via the front panel (as with a conventional ultrasonic unit), or electrically controlled from a remote digital device or computer. The GT-3 also provides computer control of the PR-2 receiver gain.

The S-80 ultrasonic unit digital interface is mounted in a separate chassis called the System Interface Cabinet (SIC). The SIC contains the signal digitization circuits and digital timing and control circuits. In addition, the General Dynamics-designed reduction electronics and array controller hardware have been mounted in spare locations inside the SIC. The following section describes the operation and function of these circuits in detail.

2.2.6 Data Reduction Electronics and Array Controller

The data reduction electronics and array controller provide the interface, synchronization, and control of the operations of the ultrasonic unit, array multiplexer, bridge controller, and data acquisition system which are required to execute the functional operations described in the system overview (Paragraph 2.1). These functions have been implemented on seven separate printed circuit assemblies (PCA). A more detailed description of the circuits and operation of each of these printed circuit cards is contained in the following paragraphs. All electrical schematics are included in the Appendix.

2.2.6.1 Array Controller, PCA-1318

The array controller contains three distinct circuits. The first consists of a 650 KHz oscillator, a counter, and the logic gates required to provide four sequential clock signals for operation and sequencing of the entire data reduction electronic circuit.

The second circuit accepts an input from the bridge scan axis encoder which provides a count pulse for each .001 inch of scan axis travel. This encoder signal is divided by the ultrasonic lattice spatial sample interval (switch selectable) in an up/down counter. The lattice spatial sample interval is currently set at .080 inch. This operation is used to synchronize the array electronic scan with bridge motion and thus assures a uniform and rectangular inspection lattice.

The third circuit is triggered by the output of the second circuit and provides the signals and timing required to accomplish an array electronic scan. It also provides the array channel number signal required by the remainder of the data reduction electronics and the data acquisition system. When triggered, this circuit issues a clear and load command to the array multiplexer shift register. It then issues a main sync pulse to the S-80 ultrasonic unit, which in turn issues a pulser sync signal to the array multiplexer transmitting gated oscillator. After 280 microseconds (Ultrasound roundtrip transit time plus guard time), the array multiplexer is shifted one position and the channel number is incremented. A main sync signal is then issued to the ultrasonic unit to begin the ultrasonic inspection cycle for the second channel of the array multiplexer. This process is continued until

all sixteen channels of the array multiplexer have been addressed. The circuit then waits for the beginning of a new array electronic scan signal.

2.2.6.2 Vector Command Generator, PCA-1270

For each ultrasonic inspection cycle, (one for each channel of the multiplexed array), the S-80 ultrasonic unit digitizes the amplitude and time (depth) parameters of the received ultrasonic signal. (The time information is not currently used but has been included to allow for pulse-echo inspection capability.) The digital ultrasonic signal parameter is sent to the vector command generator PCAs. An eight-bit parallel subtractor circuit subtracts the "just received" ultrasonic signal parameter value from a previously remembered value stored in a local memory. The difference is then compared to a programmed reference level or "threshold". If the difference exceeds the threshold, the PCA generates a vector command. This causes the "remembered" values to be transferred to the data acquisition system along with the associated length and channel number data. When this transfer is complete, the "just received" signal parameter value is written into the local memory. Two vector command generators are included in the data reduction electronics; one for the amplitude ultrasonic signal parameter and one for the time (depth) ultrasonic signal parameter.

2.2.6.3 Vector Length Counter and Data Multiplexer, PCA-1268-1

The function of the length counter is to compute and store the vector length of the data being received from the S-80 ultrasonic unit. Each time that ultrasonic data is received and the amplitude/depth values do not change (i.e., no vector command is generated), no data is sent to the data acquisition system and the count in the vector length counter is incremented by one. When a vector command is generated, however, the previously stored ultrasonic signal parameters plus the array channel number and the number of counts accumulated by the vector length counter are sent to the data acquisition system. The number of counts is always equal to the number of contiguous ultrasonic readings which had the same value. For example, if one hundred ultrasonic readings were the same, the data acquisition system would receive the unchanged value and a vector length of one hundred (rather than one hundred discrete ultrasonic readings).

A separate vector count for each channel of the multiplexed array is maintained in the length counter circuitry. The increment function is accomplished by reading the old number of counts into a parallel loading digital counter, incrementing the counter by one, and writing the new count back into the same memory location. Another function of the length counter PCA is to divide the thirty data bits being sent to the data acquisition system into two sixteen-bit words -- an acceptable format for the PDP-11/34 DMA port.

2.2.6.4 Sequence Generator, PCA 1259

The data reduction electronics system requires specific synchronization, timing, and sequencing of signals in order to properly perform its function. As an example, sending data to the PDP-11/34 DMA port requires the following operating sequence:

- Read the amplitude data from local memory
- Provide a "Data-Ready" signal to the data acquisition system
- Wait for and receive a "Data Accepted" signal from the PDP-11/34 DMA port
- Select the address/length counter outputs
- Present the "Data Ready" signal
- Wait for and receive another "Data Accepted" signal
- Write new data into the amplitude and depth memory locations
- Reset vector length to zero, then increment by 1
- Write this one value to the length counter memory

The appropriate signals for this and other sequences are provided by the sequence generator circuitry operating in conjunction with the clock signals from the array controller.

2.2.6.5 Direct Memory Access (DMA) Initialization and Control, PCA-1417

The DMA Initialization and Control circuitry allows the data acquisition system, via the bridge control microcomputer, to direct the initialization of the data reduction electronics in order to control the reduced digital data produced by the vector command generators. This is accomplished by the DMA port enable and "flush vector" signals. The "flush vector" signal allows the bridge control microcomputer to command a data transfer at the end of a bridge scan line, thereby acquiring the last vector of the scan for each channel, which otherwise would not have been transferred until the beginning of the next scan. The DMA enable signal allows the data acquisition system to inhibit extraneous data transfers which are likely to occur during the inspection setup or between scans as the bridge is being indexed to the next scanning position. This PCA also includes a monitoring circuit which transmits a fault signal to the bridge control microcomputer if for any reason the time required to transfer ultrasonic inspection data to the data acquisition system during a bridge scan motion should ever exceed 200 microseconds. This is the minimum time (excluding guard time) between data acquisitions. If data transfers were to exceed this time, the next data acquired could be faulty. The status of this signal is checked at the end of each bridge scan motion, before the bridge index and next scan motion are ordered. If this condition is ever detected, the status is transferred to the data acquisition system (via the bridge control microcomputer), and the bridge physical scan is repeated.

2.2.6.6 DMA Differential Line Driver/Receiver, PCA-1263-1

The DMA differential line driver/receiver circuits transfer digital ultrasonic inspection data to the direct memory access port of the PDP-11/34. Two handshake signals are provided which allow bidirectional communication between the PDP-11/34 and the data reduction electronics. The primary function of these circuits is to minimize or eliminate electrical/magnetic interference. This is especially important for the production CAUIS which is required to operate in an electrically "noisy" environment.

2.2.6.7 S-80 Differential Line Driver/Receiver, PCA-1264-1

This circuit provides noise immunity for the signals which transfer data from the control and data acquisition system computer to the S-80 GT-3 remote control gate module. The required handshake signals are also included. The circuitry is quite similar to that used for the DMA differential line driver/receiver card.

2.2.7 Array Transducer and Multiplexer

This section describes the array transducer, associated signal processing electronics, and the time multiplexing circuits. The following paragraphs detail the technology development up through final hardware design and implementation.

2.2.7.1 Linear Array Transducer Development

General Dynamics' efforts to design the production array transducer hardware began with a study of a prototype array produced by Southwest Research Institute (SWRI). The prototype array consisted of 25 elements spaced on .040-inch centers. Each element was .5-inch long by .032-inch wide and spaced .008-inch apart. The transducer had a 2.7 inch cylindrical focus and a frequency of 2.25 MHz. Figure 19 illustrates laboratory equipment used to investigate and record the performance of the prototype array.

Figure 20 contains schlieren photographs of the sound beam from the prototype array. Along the short (.032-inch) unfocused axis of a single array element is a relatively wide beam shape with resulting poor spatial resolution. This inferior resolution is one of the major problems involved in using a single element from a time-multiplexed array transducer. The resolution tends to "smear" flaw indications with the result that they appear larger than they really are. The obvious need is for spatial resolution to be small compared to flaw size.

In the schlieren photographs displaying the sound beams that result from simultaneously firing multiple elements of the array, the resolution is improved as the number of fired array elements increases. However, the sidelobe intensity also increases with the number of

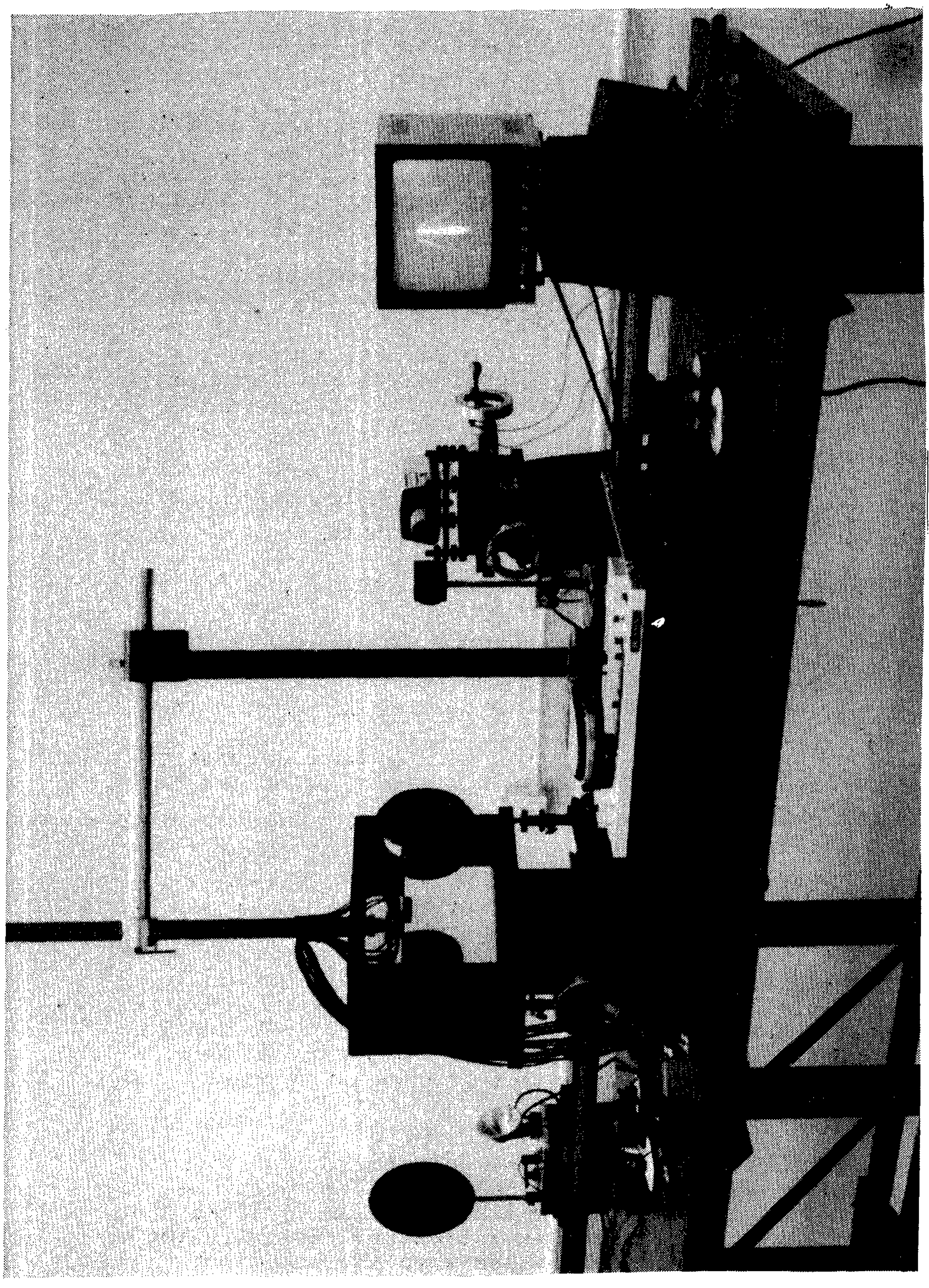
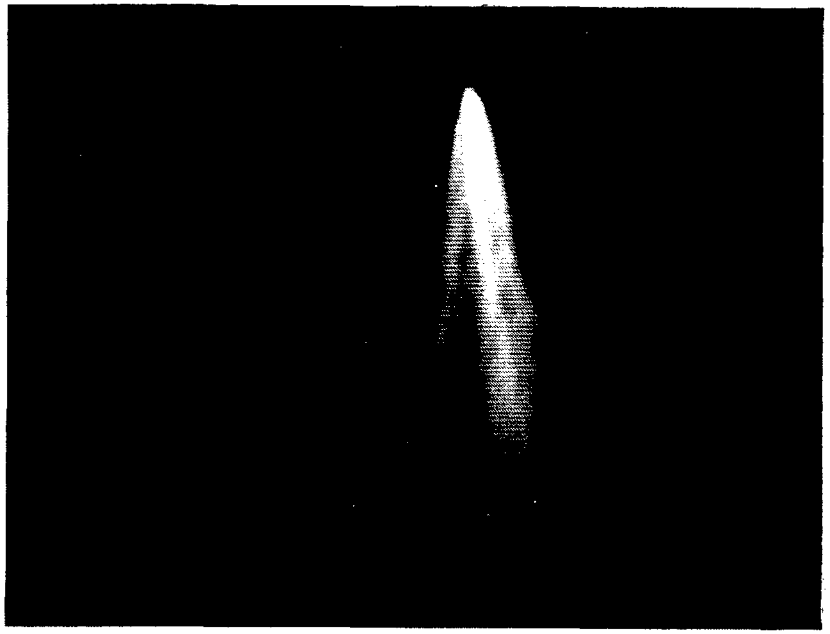
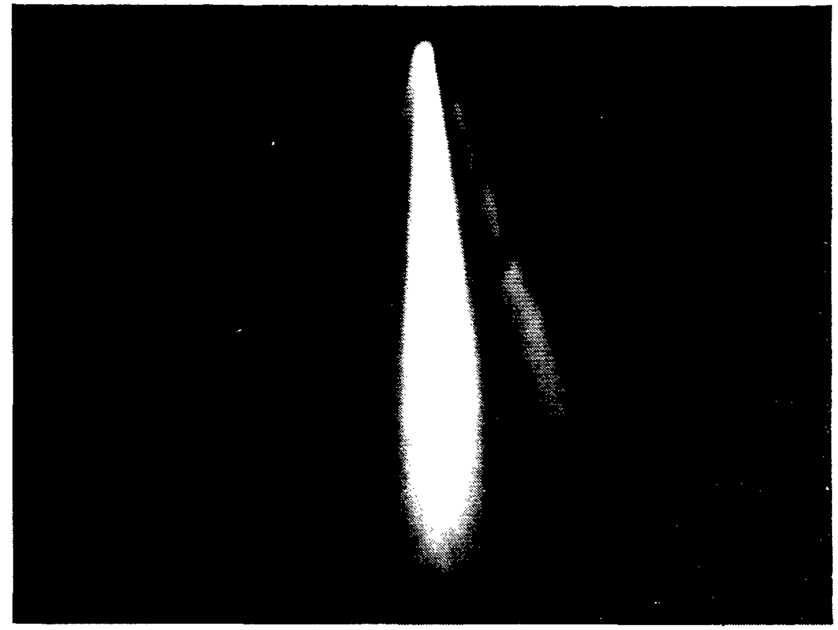


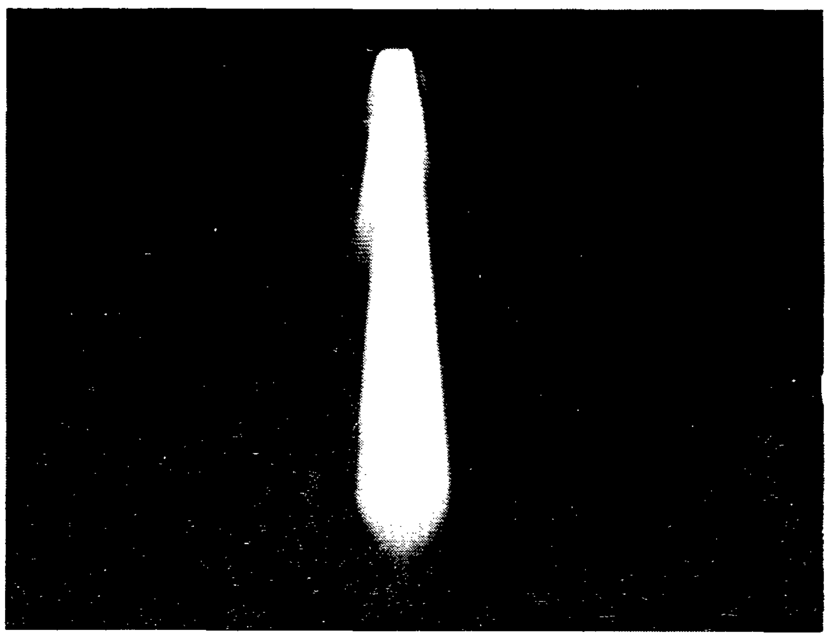
Figure 19 Real Time Schlieren System



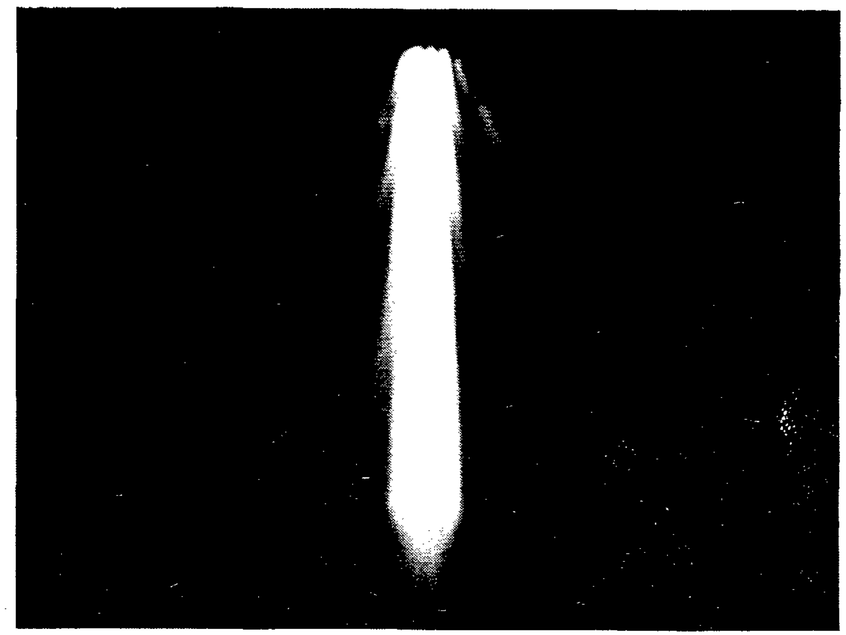
ONE ELEMENT



TWO ELEMENTS



THREE ELEMENTS



FOUR ELEMENTS

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Figure 20 Schlieren Photographs of Linear Array Sound Field

fired array elements. The sidelobe behavior is the result of diffraction from the element edges caused by the .008-inch gap between each element. Note also that beam width decreases and resolution improves as the distance from the transducer decreases.

Figure 21 is a schlieren photograph displaying the sound beam along the focused axis of the array element. Although in this photograph the sound beam is generally better controlled, note that the crystal has been excited in complex multiple vibrational modes. This is the reason for the distinctive beam structure at the Fresnel region of the sound beam near the transducer face. This distinctive beam structure is due to the long, relatively thin design of the transducer element. The beam shape does not improve until very close to the focal point. From this it can be deduced that a more sharply focused lens may provide better resolution closer to the transducer face.

Figure 21 Lens Focused Sound Beam of Linear Array Transducer

From the above data, four key points can be concluded:

1. Each element should be made as large as the inspection spatial sample rate of .080-inch will permit.

2. Firing multiple elements will improve spatial resolution.

3. Spacing between elements should be minimized until crosstalk begins to increase.

4. The array should be operated as close to the part as is practical.

To perform a quantitative assessment of array element performance, the equipment displayed in Figure 22 was utilized. This equipment is a high-resolution, high dynamic-range sound beam profiler. This profiler allows accurate measurement of transducer sound beam characteristics. The resulting data is used to establish optimum element parameters and can be used to determine transducer performance.

Figure 23 is a block diagram showing the signal processing and profiling method used in the system. The instrument uses a plastic water tank outfitted with a scanning mechanism and a .010-inch diameter acoustic microprobe.

Figure 24 is an example of the calibrated output format of the sound beam profiler showing the high resolution attainable. The unit is operated with a calibrated attenuator. The angular displacement of the microprobe transducer is plotted on the X-axis of the graph paper by an X-Y recorder.

The SWRI prototype transducer array was tested for array element uniformity and sound beam profile. The data obtained is summarized in Table 1. The data shows that the array response was uniform to roughly ± 2 dB over a selected grouping of six elements. The array profiles also show that an acceptable sound beam width can be obtained at about 6-cm range by cophasing either four or six elements of the array, giving a beamwidth dimension of from .160 to .240 inch. The focused dimension of the array gives an acceptable beam focus, but the focal length was longer than desired because of the required ultrasound transit time through a water

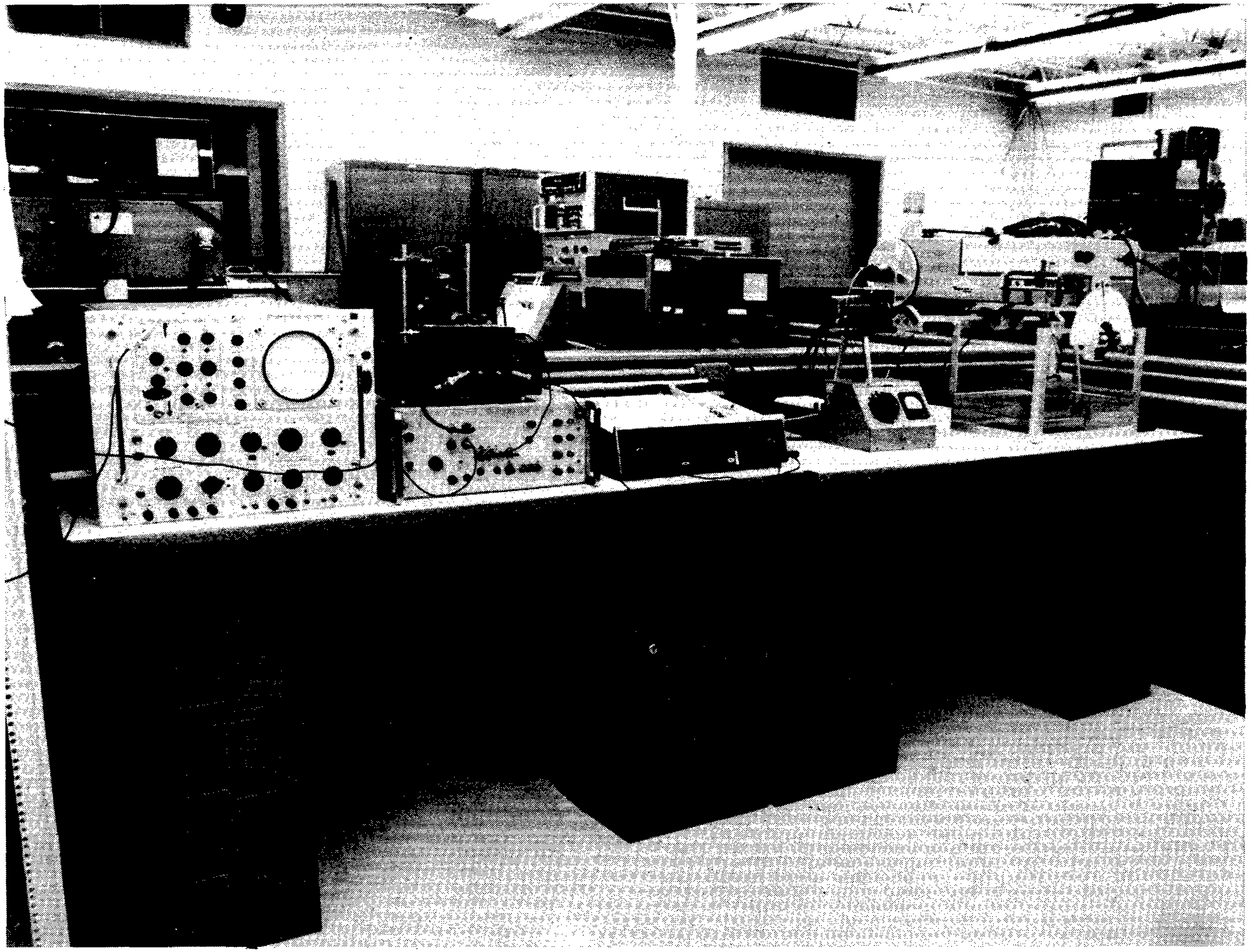


Figure 22 Laboratory Sound Beam Profiler Using High Dynamic Range Signal Processing

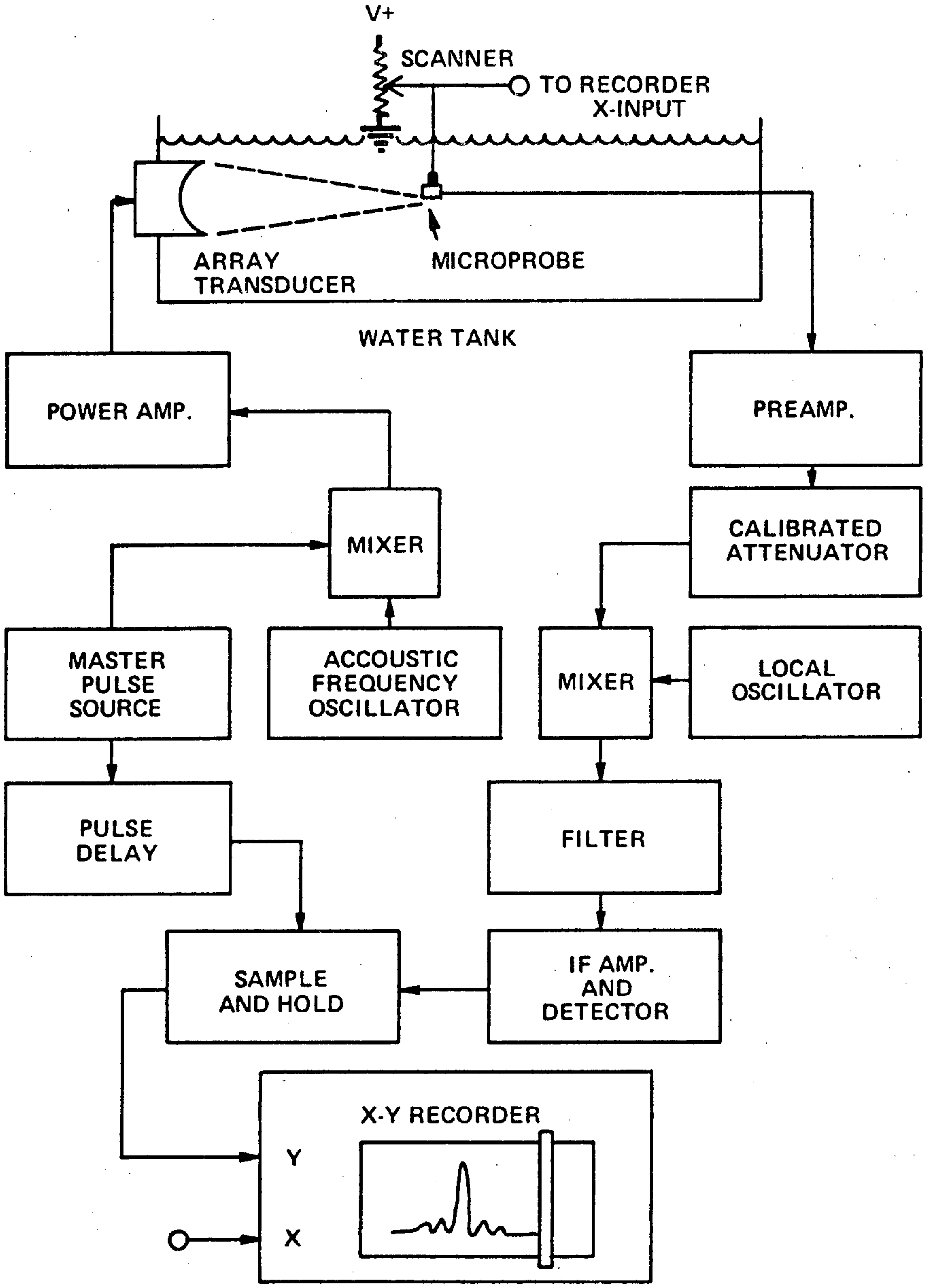


Figure 23 Signal Processing Technique for Sound Beam Profiler

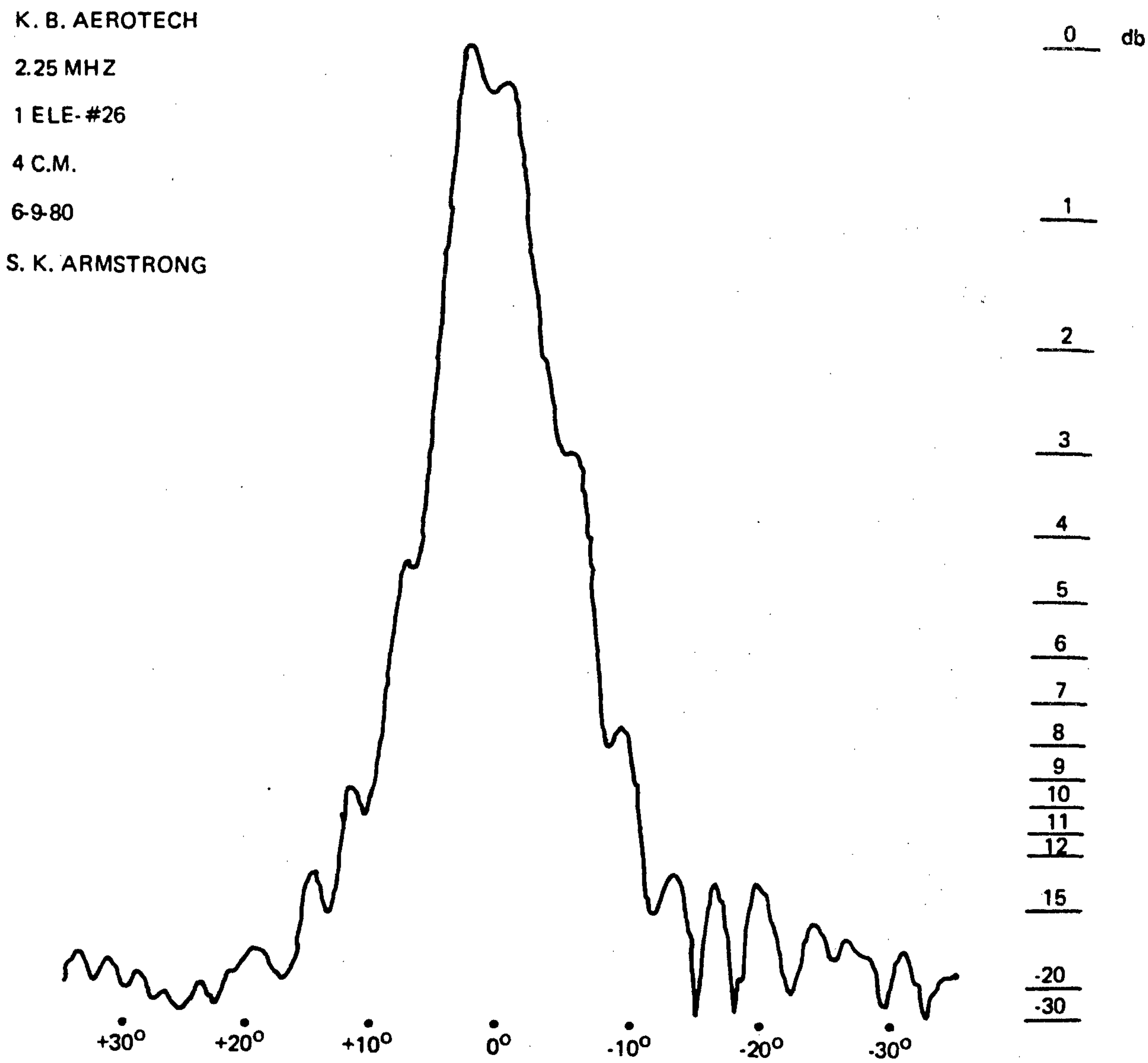


Figure 24 Calibrated Sound Beam Profiler

Table 1 SWRI ARRAY UNIFORMITY AND SOUND BEAM PROFILE DATA

SWRI TRANSDUCER UNIFORMITY AT 2.25 MHz

PULSER #	TRANSDUCER ELEMENT #	OUTPUT VOLTAGE	INTENSITY (dB) AT 2.25 MHz
1	10	270	-3.0
1	11	270	-3.0
1	12	270	-0.5
1	13	270	-1.5
1	14	270	-1.5
1	15	270	0

SWRI MULTIELEMENT SOUND BEAM PROFILE ANALYSIS AT 2.25 MHz

NO. ELEMENTS	RANGE (CM)	LATERAL 6dB BEAM WIDTH	SIDE LOBES (dB AT ANGLE°)
4	5	13°	-15 at ± 13
4	6	13°	-15 at ± 15
4	7	13°	-15 at ± 18
6	5	9°	-11 at ± 12
6	6	9°	-11 at ± 11
6	7	9°	-11 at ± 11

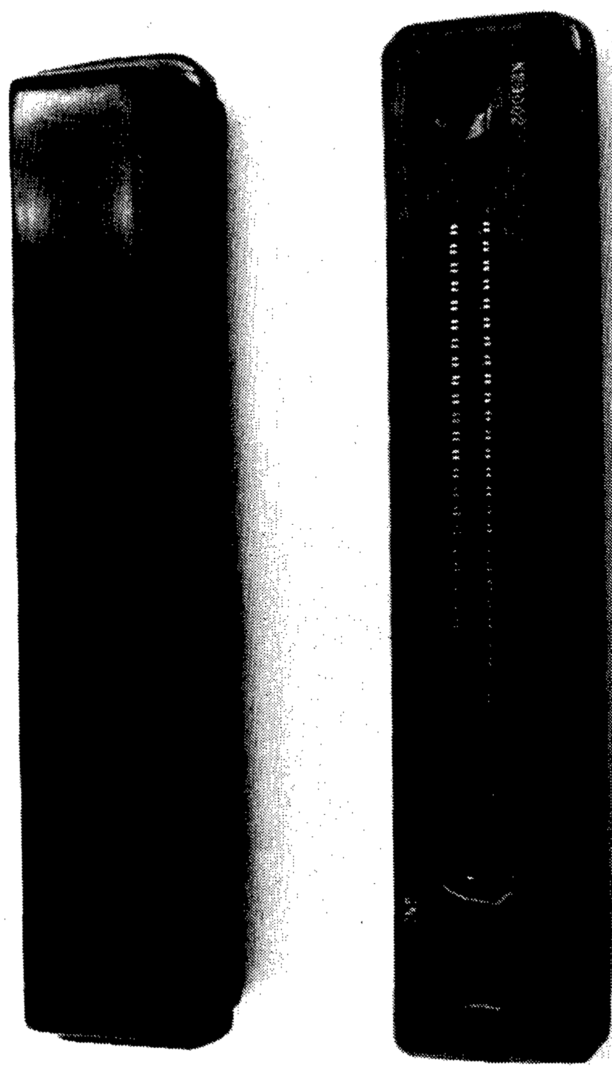


Figure 25 K.B. Aerotech Medical Real-Time Scanner Transducer Arrays

path longer than 5 cm. Also, the shorter the focal length, the closer the reflector plate can be to the transducer array and the higher the sensitivity of the entire system.

2.2.7.2 Production Transducer Array

Based on data generated with the above measurements and operational requirements, a high-efficiency air-backed 37-element 2.25 MHz linear array transducer was designed. This design incorporates .500-inch separation between elements and utilizes a bonded plastic lens, metal housing, a single multipin RF connector, and electrical interface shielding.

This design was discussed with several manufacturers of ultrasonic transducers with the understanding that the proposed transducer array would be used for defense industry production and should be a replaceable maintenance item. K.B. Aerotech was the sole respondent to our proposed design. However, after estimating the cost to build two copies of the special transducer, K.B. Aerotech recommended one of its standard off-the-shelf medical real-time scanner transducer arrays. The proposed array is currently used in Unirad medical ultrasound scanners and is a 2.25 MHz foam-backed PZT-5A transducer with .080 element centers and .008-inch element separation, all of which met General Dynamics' design requirements.

Two of the arrays shown in Figure 25 were loaned by K.B. Aerotech. The results of lateral, unfocused axis profile measurements of element groups with the medical array were far superior to the profiles obtained from the SWRI array. The results are tabulated in Tables 2 and 3.

The next step in implementing this design was to construct a plastic lens for the unfocused medical array. Several plastics were considered for the lens. Polystyrene was finally chosen because of its low absorption characteristics, its availability, and ease of machining.

A polystyrene block was machined into a cylindrical lens with a radius of curvature of .750-inch. The lens was then attached to the array, and profile measurements

Table 2 K.B. AEROTECH ARRAY LATERAL SOUND PROFILES AT 2.25 MHz

NO. ELEMENTS	RANGE (CM)	LATERAL 6 dB BEAMWIDTH	SIDE LOBE INTENSITY (dB)
2	3	13.0°	less than -18
2	4	12.7°	less than -18
2	5	12.0°	less than -18
3	3	10.0°	less than -20
3	4	9.3°	less than -20
3	5	9.0°	less than -20
4	3	12.7°	less than -21
4	4	10.0°	less than -21
4	5	8.0°	less than -21

Table 3 K. B. AEROTECH ARRAY PERPENDICULAR SOUND PROFILES UNFOCUSED AT 2.25 MHz

NO. ELEMENTS	RANGE (CM)	6 dB BEAMWIDTH
1	4	15.8°
1	5	12.7°
1	6	10.3°
2	4	15.5°
2	5	12.7°
2	6	10.3°
3	3	20.3°
3	4	15.1°
3	5	12.7°
3	6	10.3°
4	3	22.4°
4	4	15.5°
4	5	12.7°
4	6	10.3°

were made. The results shown in Table 4 indicate that the medical-type array with the plastic lens shows remarkably narrow beam width at a focal distance between 4 and 5 cm. This beam-width meets the operational requirement of less than 2-inch (5.08 cm) transducer-to-reflector-plate distance. The plastic lens with medical array arrangement was also compared to the efficiency of the Southwest Research Institute array for sound production. The medical array with the General Dynamics lens was 21 dB more efficient at 2.25 MHz than the Southwest Research Institute array. This gives a total system efficiency gain of +42dB (round trip) over the highly damped SWRI linear array.

The final design selected for use in the CAUIS was the K.B. Aerotech transducer array in a sturdy housing with a plastic lens and a single multipin RF connector. The K.B. Aerotech off-the-shelf medical array consists of 64 elements. For reasons discussed in detail below, the General Dynamics design utilizes 19 of these transducer elements for optimum CAUIS application. The lens and transducer housing design are shown in Figure 26. Figure 27 shows two views of the transducer housing and lens assembly.

2.2.7.3 Selecting the Optimum Number of Channels

The development of the multiplexer electronics began with an investigation into the optimum number of channels to be time-multiplexed. A number of factors entered into the decision to utilize 19 of the K.B. Aerotech transducer array's 64 available elements. The object of time-multiplexing is to decrease inspection time. This can be achieved by grouping a number of transducers within a single scanning surface and multiplexing the electronics, thereby physically enlarging the effective scanning surface. Thus, the increase in the number of time-multiplexed channels would result in reduced inspection time. However, an upper limit on the number of channels that can be combined exists when scan speed, the spatial sample rate, and the maximum data acquisition rate are held constant. Any increase beyond this number of channels forces a decrease in scan speed or an increase in the data acquisition spatial sample interval -- an interval fixed by the inspection requirements.

Table 4 K. B. AEROTECH ARRAY PERPENDICULAR SOUND PROFILES LENS FOCUSED 5 CM AT 2.25 MHz

NO. ELEMENTS	RANGE(CM)	6 dB BEAMWIDTH
2	3	8.6°
2	4	4.8°
2	5	4.3°
3	3	7.9°
3	4	4.5°
3	5	4.3°
4	3	8.3°
4	4	5.2°
4	5	4.3°

The upper limit of the scan speed is imposed by the round-trip transit time of the ultrasonic energy. Because of the thickness of the composite panels to be inspected combined with the part-to-reflector-plate spacing requirements and the fixed depth of the focal zone, operating the transducer closer than 2 inches to the reflector plate is impractical. This corresponds to a round-trip transit time for the ultrasonic energy of approximately 75 microseconds when the ultrasonic pulse duration is approximately 8 microseconds. A 25 micro-second "guard" time was assumed, yielding 100 micro-seconds as the effective round-trip transit time. To prevent geometric distortion of the inspection results, the array transducer electronic scan must also be completed in less than the time required to mechanically scan one-half of the spatial sample interval. Thus, the round trip transit time of the ultrasonic energy imposes an upper limit on the data acquisition rate and therefore the scan speed.

In practice, the maximum scan speed limit was established by 2nd and 3rd time around reflections cross coupling into adjacent channels. This limit resulted in a maximum scan axis speed of 8 inches per second at 3 KHz repetition rate. The 3 KHz repetition rate allows sufficient time for the transmitted sound energy to be reflected back to the array transducer and processed by the S-80 Reflectoscope for varying thicknesses of current F-16 production composites.

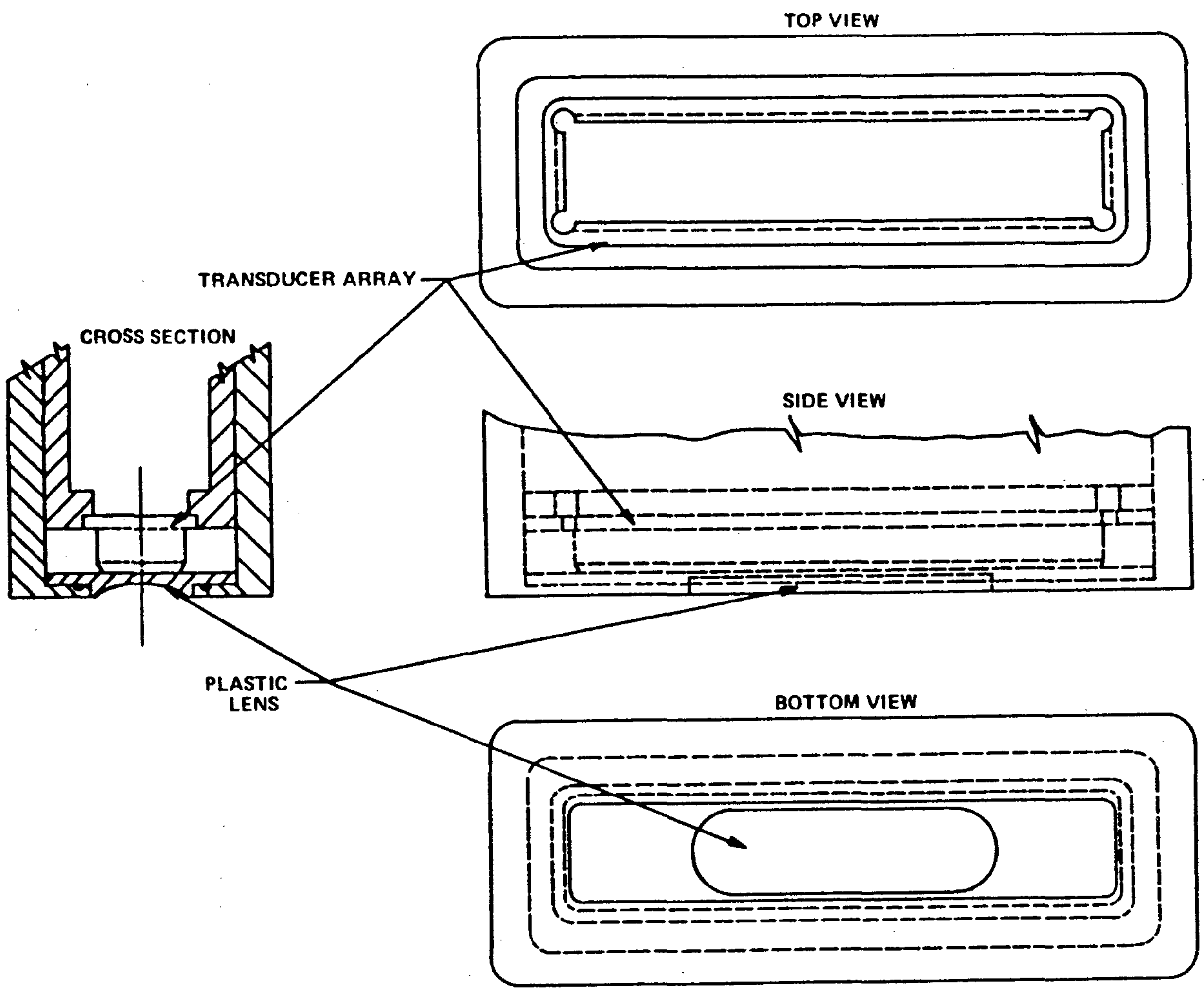


Figure 26 Production Multiplexed Array Transducer Head

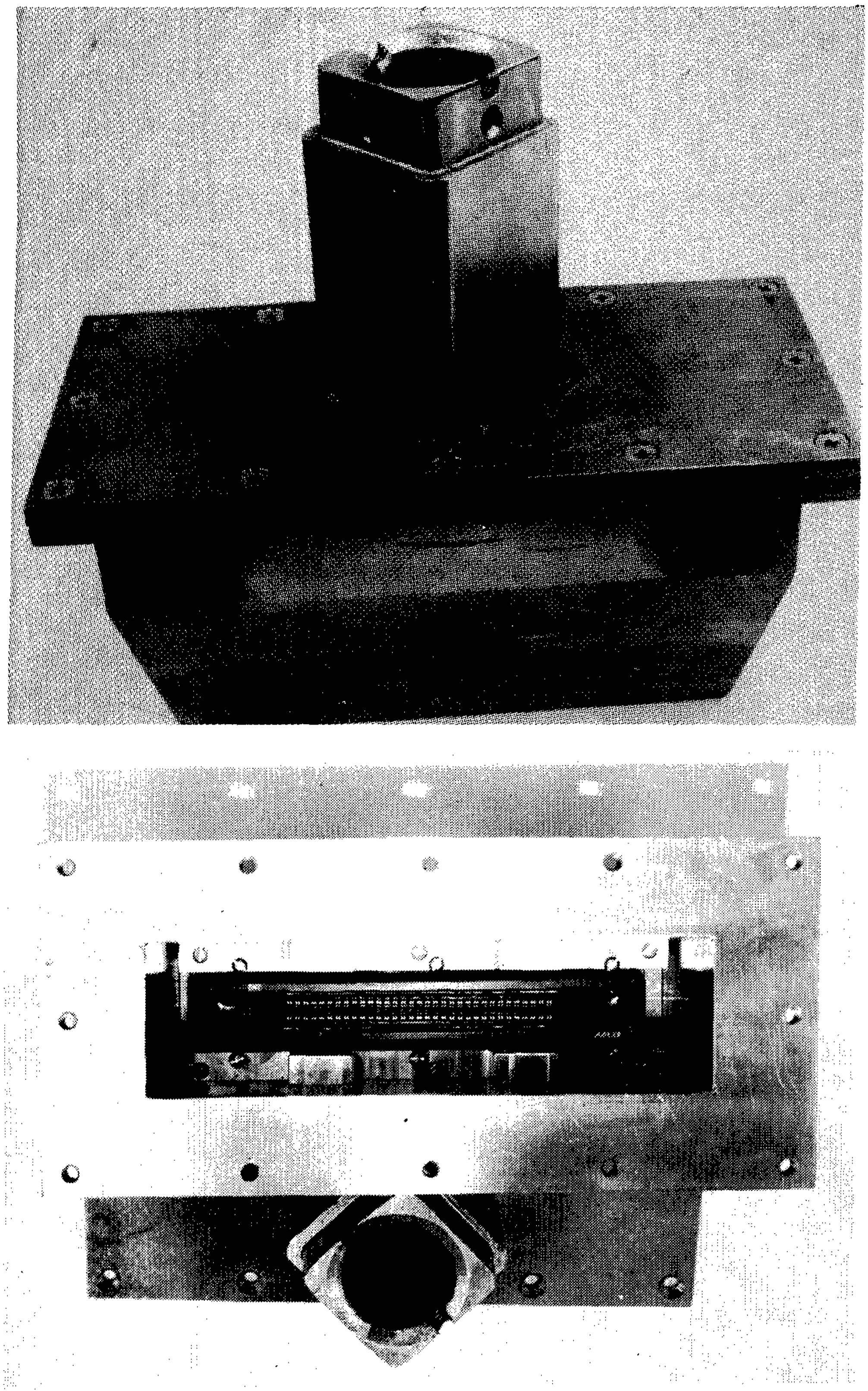


Figure 27 Transducer Head

A significant increase in cost is required in the development and maintenance of time-multiplexed array digital interfaces, computer hardware, and computer software when the number of channels is increased from 2 to 3, 4 to 5, 8 to 9, 16 to 17, and 32 to 33. All of the above factors led to the selection of 16 as the optimum number of channels to be utilized. This required the use of [16 + (number of channels/element) - 1] elements of the array. The multiplexer hardware was designed and fabricated to allow use of up to 8 elements/channel. Four elements/channel, (a total of 19 elements for the 16 channels), however, were selected for production inspections utilizing CAUIS time multiplexed array system with a spatial sample interval of .080-inch, in accordance with existing requirements.

2.2.7.4 CAUIS Production Multiplexer Electronics Development

A study was undertaken to determine the feasibility of an advanced, highly miniaturized multiplexer. by designing the multiplexer to fit inside the transducer array head, many potential problems associated with the large number of submersed flexing coaxial cables and connectors would be eliminated. Also, interchangeability between single-transducer and time-multiplexed array operation would be greatly simplified.

Present immersion inspections of graphite/epoxy laminates utilize a reflector-plate technique involving a high voltage spike-pulse drive and a conventional wideband receiver designed for true pulse-echo ranging. Incorporating this type system into a multiple-channel array transducer would require a separate pulser for each channel since existing technology does not allow multiplexing a single pulser between transducer elements. But a separate pulser for all 16 channels of the array transducer would be physically cumbersome and would preclude packaging the multiplexer within the array head. However, a low voltage RF waveform drive of several cycles duration has been successfully employed in the laboratory to produce 12 dB greater acoustic power output than an equal voltage spike-pulse. Further gains in sensitivity may be achieved by using a non-damped acoustically matched transducer. These improvements lower the drive-voltage required to produce the same acoustic power output. And the lower drive-voltage requirement opens the door to employing a single-gated oscillator which can be multiplexed through FET switches to activate the transducer while achieving

the same or better acoustic sensitivity. A survey of available electronic devices indicates that present silicon technology limits FET switches to less than 40-volt peak-to-peak signal operation.

Single-chip preamplifiers were also surveyed. The best devices available achieve a gain of approximately 20dB, a noise figure of approximately 10 dB, and a dynamic range of less than 40 dB. Experience has shown that a dynamic range of 60 dB is needed for pulse-echo reflector-plate inspection over the wide range of part thicknesses encountered with F-16 vertical stabilizer composite skins. A noise figure of less than 5 dB is also required. Because of these requirements, a multicomponent preamplifier using special low-noise, high dynamic range transitors must be employed. These devices use microwave technology and are available off-the-shelf far more economically than would be the cost of in-house development of a special-purpose preamp.

The physical packaging of a commercial preamplifier requires more space than is available to allow mounting within the array head. It was decided, therefore, to mount the preamplifier at the top of the search tube mast, Figure 28. The signal cables were routed inside the mast and connected to the transducer by a single multichannel RF connector. The transducer array head was then precision-mounted to the lower end of the search tube mast. This design does not allow angular movement of the array head; however, angular movements are not appropriate for the time-multiplexed transducer scan since the array is designed for inspection of planar parts with a horizontal reflector-plate.

When needed, angular motion of a single transducer can be performed simply by substituting a separate search tube containing transducer angular motion capability in place of the time-multiplexed array search tube.

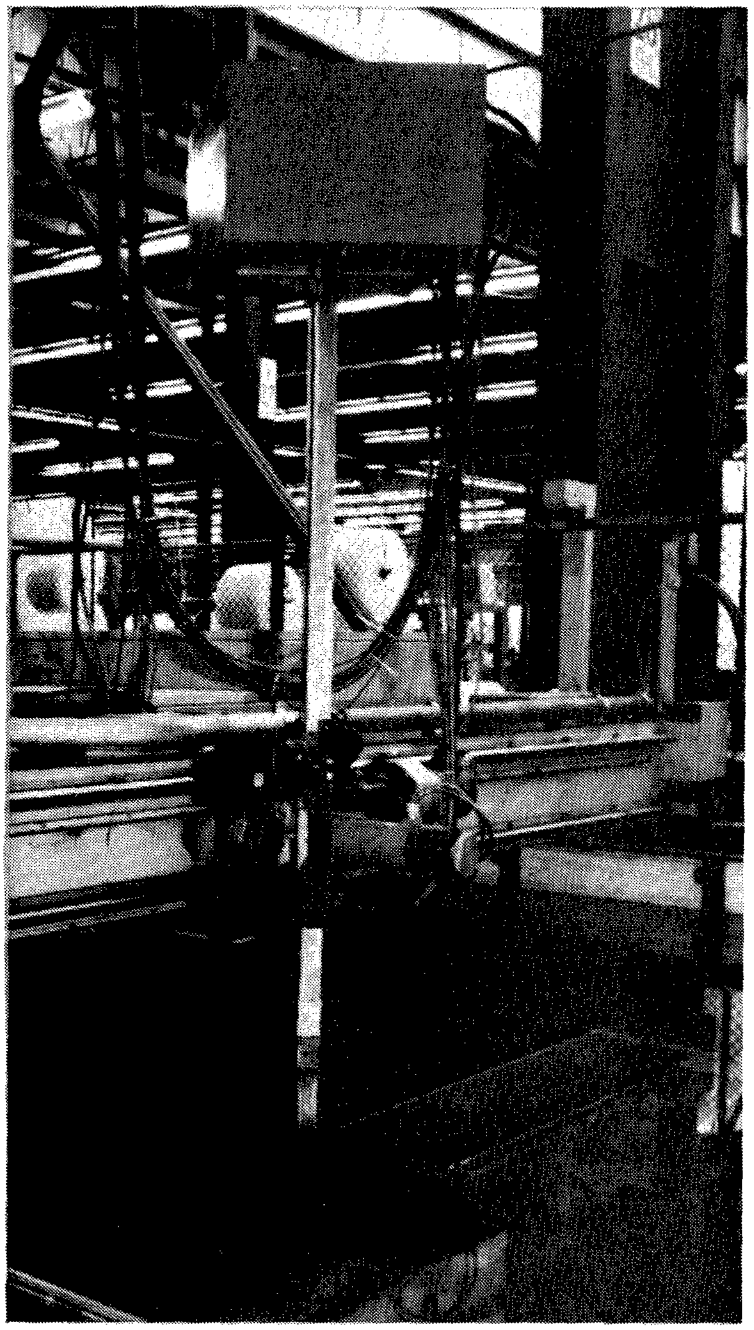


Figure 28 Preamplifier Mounted on Top of Search Tube Mast

The power available from an output short-circuit-protected amplifier modified for research during this project was measured with a matched transducer connected to the output. The maximum peak-to-peak voltage of the amplifier, as measured with an oscilloscope, was 38 v peak-to-peak, giving a root-mean-square power of

$$PRMS = \frac{V2_{rms}}{R} = 3.75 \text{ Watts,}$$

Where R is a 48-ohm load and Vrms is (Vpp/2) (.707).

In decibel notation, 1mW = 0 dBm by convention, so 3.75 Watts would be written 36 dBm. If the transducer's round trip insertion loss is known, a quick calculation can be made of the acoustic power that can be developed by the transmitter. Estimating conservatively for an air-backed transducer, if the one-way insertion loss is -21 dB, by subtracting 21 dB of insertion loss from the power output of the amplifier the result is +15dBm of acoustic power, or 31.6 mW.

An output power of 30 mW acoustic was estimated to be adequate to inspect either graphite skins with reflector plate mode or bonded assemblies in through transmission mode. This was concluded from former research work. A gated oscillator transmitter and buffer amplifier were designed to meet this power requirement and to produce a very high on/off ratio pulse. The oscillator and buffer amplifier are very compact and have a high degree of on/off dB separation while driving approximately 1 ampere of current through a 50-ohm resistive load. The waveform from the gated oscillator and buffer amplifier operated at 2.25 MHz is shown in Figure 29.

2.2.7.5 Multiplexed Array Final Hardware Design

The ultrasonic transducer transmitting/receiving array consists of 19 individual piezoelectric crystal elements .080-inch apart forming a 16-channel array 1.28 inches in length. A "pulser sync" timing signal synchronizes a gated 2.25 MHz oscillator that excites the individual crystals. The reflected ultrasonic

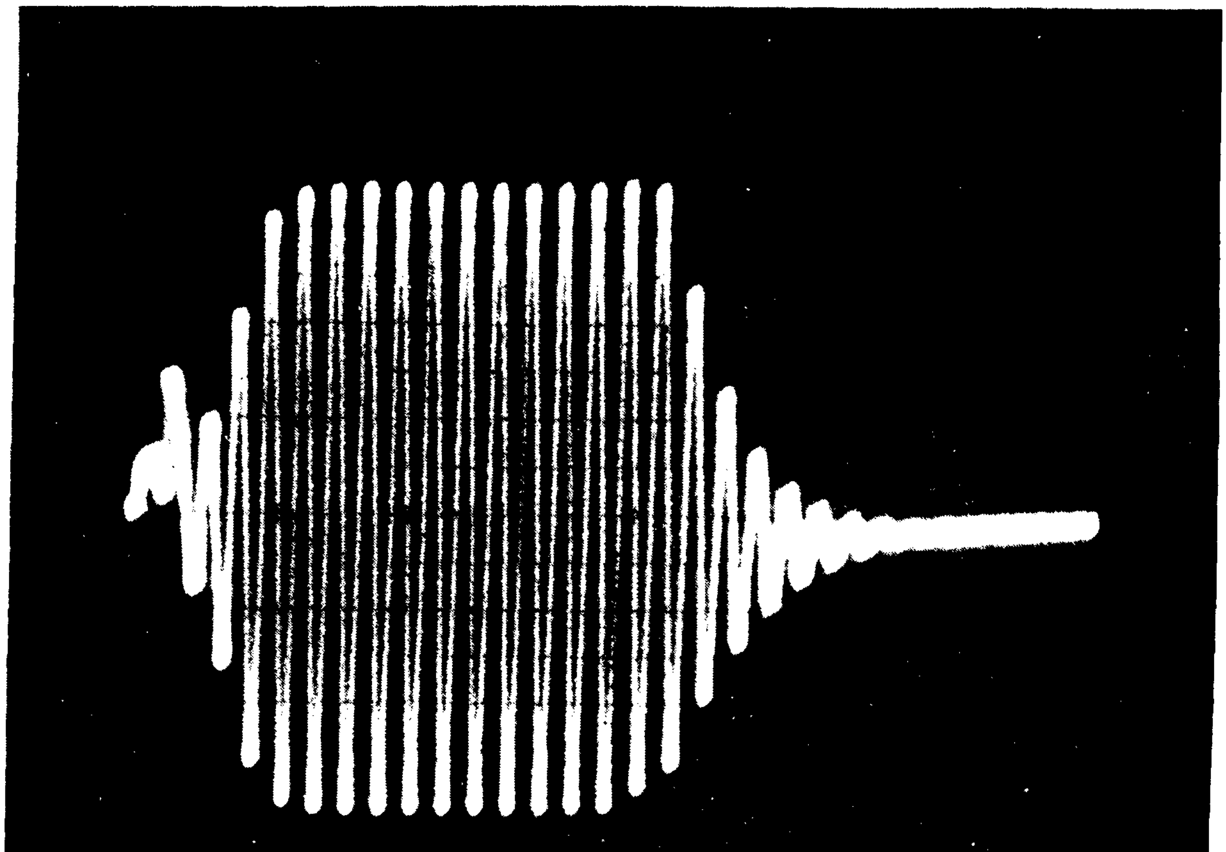


Figure 29 Gated RF Oscillator Waveform at 2.25 MHz

energy re-excites the piezoelectric crystals and the multiplexer electronics processes the resulting data in the following sequence:

1. The reflected signal enters a vector power combiner.

2. The vector power combiner output signal passes through a high-speed multiplexing attenuator.

3. The attenuator output signal passes through a 36 dB Amplica Pre-amplifier.

4. The 2.25 MHz RF reflected signal passes through a set of manually operated attenuators.

5. The output signal of the manually operated attenuators passes to the S-80 Reflectoscope receiver (PR-2 module).

An overall block diagram of the time-multiplexed array production hardware is shown in Figure 30. The system consists of two functional subsystems:

- o Ultrasonic subsystem - comprised of a gated RF transmitter, 24 transmit Field Effect Transistor (FET) switches, an array transducer, 24 receiver FET switches, a 24-input power combiner, a high-speed multiplexing attenuator, a preamplifier (Amplica), and a set of manually operated attenuators.

- o Multiplexer subsystem - comprised of a multiplexer logic printed circuitboard assembly.

2.2.7.5.1 Ultrasonic Subsystem

1) Gated Oscillator - A schematic diagram of the gated oscillator (transmitter) is shown in the Appendix. The system "pulser sync" pulse triggers an RF burst from the gated oscillator which is delayed for a fixed time. The burst length is internally adjustable down to 2 cycles. The RF burst amplitude is adjustable to greater than 25 volts.

2) Transmit FET switches - The transmit FET switches provide a time-multiplexed array capability. The preselected crystal-activation pattern from the multiplexer logic board selects the correct transducer elements for excitation via the transmit FET switches. The remaining elements are isolated from the gated transmitter except during the RF burst by the transmit FET switches. This avoids loading of the echo signal by the output impedance of the gated transmitter.

3) Transducer array - The insertion loss for the K.B. Aerotech medical array transducer in water with a 2-inch focal length cylindrical lens focused on the reflector plate is 20 dB. The efficiency of the transducer allows the array to inspect graphite parts up to 0.5 inch thick with a high dynamic range.

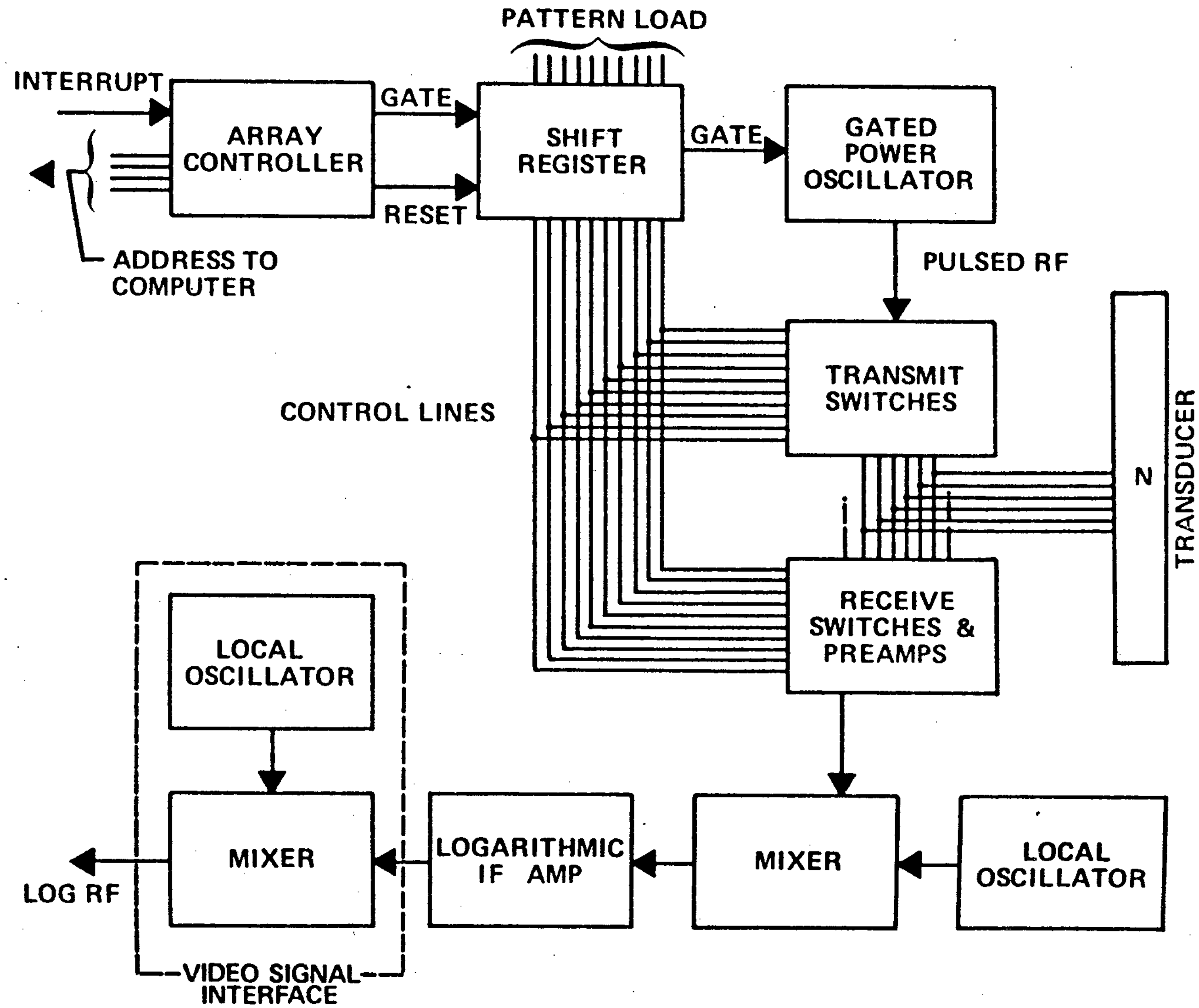


Figure 30 Transmit/Receive Switch Type Time Multiplexed Signal Processing System

4) Receive FET Switches - Each transducer element is connected to one input of the 24-input power combiner through FET switches. These FET switches select the power combiner inputs corresponding to the excited transducer elements. Figure 31 illustrates functional relationships of both the transmit and receive FET switches.

5) High-Speed Multiplexing Attenuator - A General Dynamics-designed 16-channel multiplexed attenuator adjusts each channel (4 elements) to "balance" the electrical differences of each transducer element. A schematic diagram of the multiplexing attenuator is shown in the Appendix.

6) Preamplifier - The preamplifier is an Amplica, Inc., wideband amplifier with a high-frequency roll-off. The amplifier has 36-dB gain from 2MHz to 26 MHz with 40 dB/decade roll-off, a 2-dB noise figure, and a VSWR less than 1.5 for both input and output. The preamplifier's minimum discernible signal of -122 dBm assures wide dynamic range for ultrasonic inspection of graphite/epoxy composite parts.

7) Externally Operated Attenuators - Two TEXSCAN, Inc. miniature rotary attenuators provide 0 to 10 dB of attenuation in 1 dB steps, and 0 to 60 dB of attenuation in 10 dB steps. These attenuators are controlled via externally mounted knobs. Gain of the RF signal can be adjusted just prior to processing by the S-80 Reflectoscope.

2.2.7.5.2 Multiplexer Subsystem

The schematic diagram of the multiplexer digital logic board is shown in the Appendix. On command of the System Interface Cabinet, the transmit and receive sections of the logic board load the preselected transducer-activation patterns into the shift registers. The transmit and receive patterns may be independently selected. The SIC then clocks the shift registers (once for each array channel) and the transmit/receive FET switches are sequentially selected according to the preselected pattern.

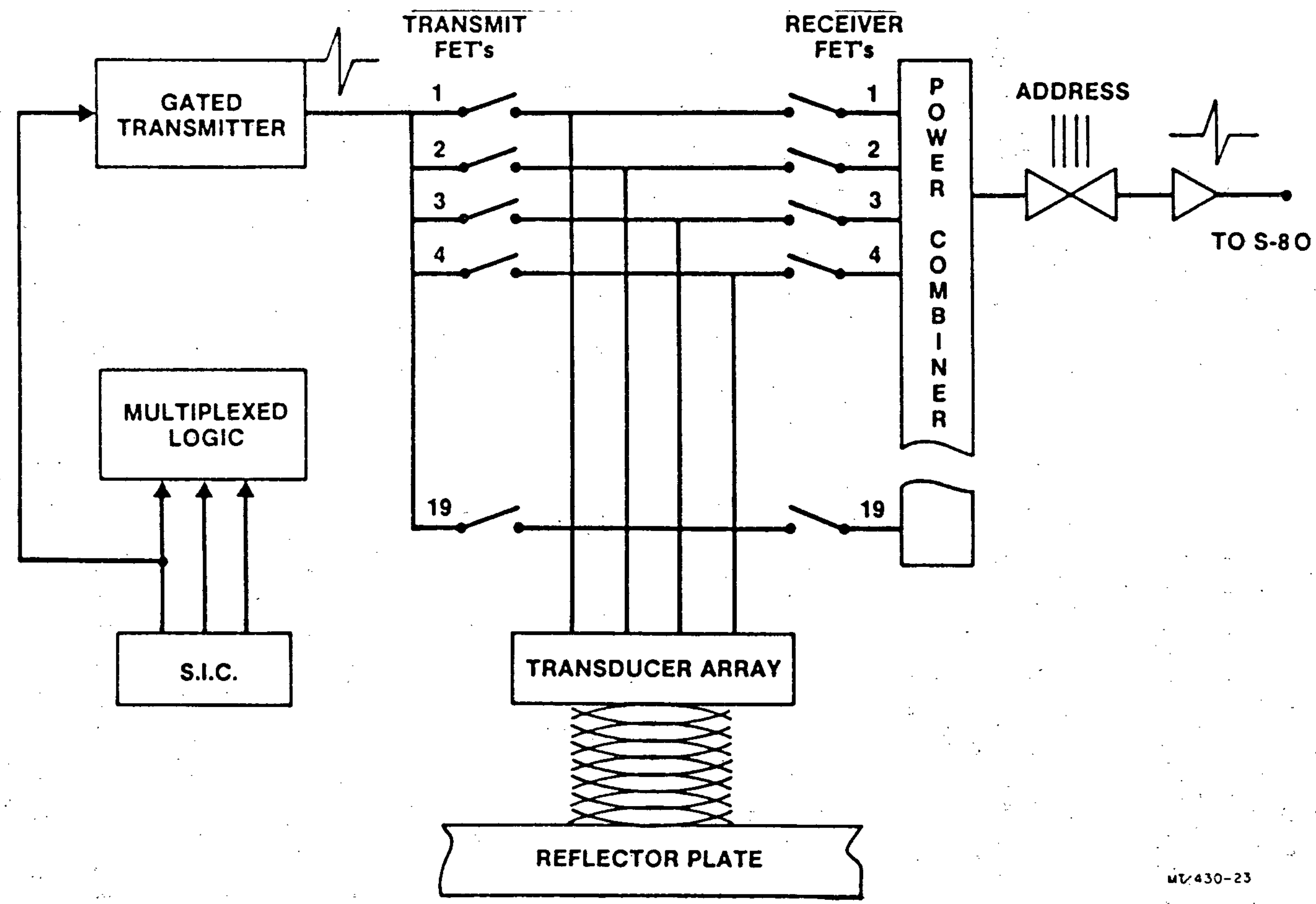


Figure 31 Transmit and Receive FET Switches Functional Relationship

2.3 Production CAUIS Software Design

The Computer Automated Ultrasonic Inspection system is a dual computer-controlled system. The CAUIS utilizes high technology communication interfaces between computers and components. Scan control, data acquisition and data management are handled by a DEC PDP-11/34 minicomputer; however, the bridge is actually driven by an Intel 80/30 Single Board Computer (SBC).

Computer communication is through a standard RS 232C serial interface with custom-built RS 422 differential line driver and receiver boards. Transmission rates are at 9600 bits/second. All communication is through two lines - a transmit line and a receive line. Handshaking is accomplished with software in each computer.

In addition to intercomputer communications, each computer talks to other components within the system. The 11/34 minicomputer acquires inspection data from the ultrasonic hardware through the Systems Interface Cabinet (SIC). During an ultrasonic scan, sixteen data lines transmit directly to the 11/34. These data lines are linked to a Direct Memory Access controller for a maximum data-transfer rate during acquisition. Two handshake lines provide data acquisition from the SIC. These two lines are for "data ready" (from the SIC), and "data accepted" (to the SIC).

The Intel microcomputer communicates with the ultrasonic hardware through the SIC with parallel I/O lines. Seven discrete I/O lines are employed -- five output lines from the microcomputer to the System Interface Cabinet and two input lines from the SIC to the microcomputer. All components on the bridge are controlled by the Intel microcomputer. Bridge motion is controlled by the microcomputer by transmitting commands onto the Intel multibus to the motor control card located in the bridge control microcomputer cabinet.

2.3.1 Intel 80/30 Microcomputer

The heart of the bridge control microcomputer is an Intel single board computer using a high-speed 8085 HA-2 microprocessor chip with enough Random Access Memory (RAM), Read Only Memory (ROM), and enough serial and parallel I/O ports for 75% additional growth.

The microcomputer runs the bridge in two distinct modes - Local and Computer. In the LOCAL mode, all scan parameters are keyed in through the front panel. This mode is used to isolate problems with the bridge motion controller and for set-up/calibration of the S-80 ultrasonic subsystem. Actual ultrasonic scanning cannot take place in this mode. In computer mode, the Intel microcomputer receives all scan parameters from the PDP 11/34. The part to be inspected is placed in the immersion tank. Placement is not critical since the microcomputer has a floating zero or reference point anywhere in the tank; however, the part must be placed so that the scan can begin at a point off of the home limit switches. Part coordinates are then defined by moving the bridge over the part and reading the X and Y displays on the front panel.

The X and Y coordinates that define the part are entered into the 11/34 minicomputer through the VT-100 terminal. A minimum of three points are required to define a part. Each part is also defined to the 11/34 by its part number and its unique serial number.

In addition to defining the part coordinates and identifiers, the inspector must set up the S-80 Reflectoscope for the specific type of part. Once this is accomplished, the inspector initiates the part inspection via the VT-100 operator terminal.

Upon initiation of the scan, the PDP-11/34 sends a series of codes to the Intel microcomputer to begin performing all necessary functions for bridge motion and ultrasonic control.

The PDP-11/34 sends the first scan line coordinates to the Intel microcomputer. The microcomputer then takes control of the bridge motion and executes the scan. This leaves the PDP-11/34 free to acquire inspection data.

At the end of the scan, the Intel microcomputer checks lockout status to verify that all inspection data was transmitted and received on the parallel input lines and sends the status to the PDP-11/34. This status check signals the end of scan to the PDP-11/34 which then sends the next scan coordinates to the Intel microcomputer and the cycle is repeated.

Upon completion of a part inspection, the Tektran bridge automatically returns to the pre-programmed starting reference point. The ultrasonic inspection results are requested by the inspector via the VT-100 operator terminal and a hardcopy printout is produced by a 72-inch Versatec Plotter. From this plot, the operator can determine the disposition of the inspected part. The operator then sends the inspection results electronically to the Nondestructive Evaluation Terminal for further analysis and archiving.

2.3.2 CAUIS Software

Software developed for the CAUIS is divided into two major sections:

- Scan Control/Data Acquisition and Data Management

- Bridge Control

As illustrated in Figure 32, the two software systems are interrelated in that the bridge control microcomputer receives status information from the ultrasonic hardware and transmits this information back to the data acquisition system for scanning position registration.

2.3.3 Data Acquisition Software

Data acquisition has the primary function of gathering ultrasonics data in the form of amplitude, transducer channel, and vector length from the ultrasonics hardware. The various control and data transfer functions are handled with software modules that are currently catagorized into four major functions:

SCIM - The Scan Control Input Module has the primary task of controlling the three other subtasks as well as performing related data management functions.

SCAN - This module controls the scanning operation and the ACQ subtask.

ACQ - This data acquisition module accepts and formats ultrasonics data to disk storage through the DR11-B Direct Memory Access port.

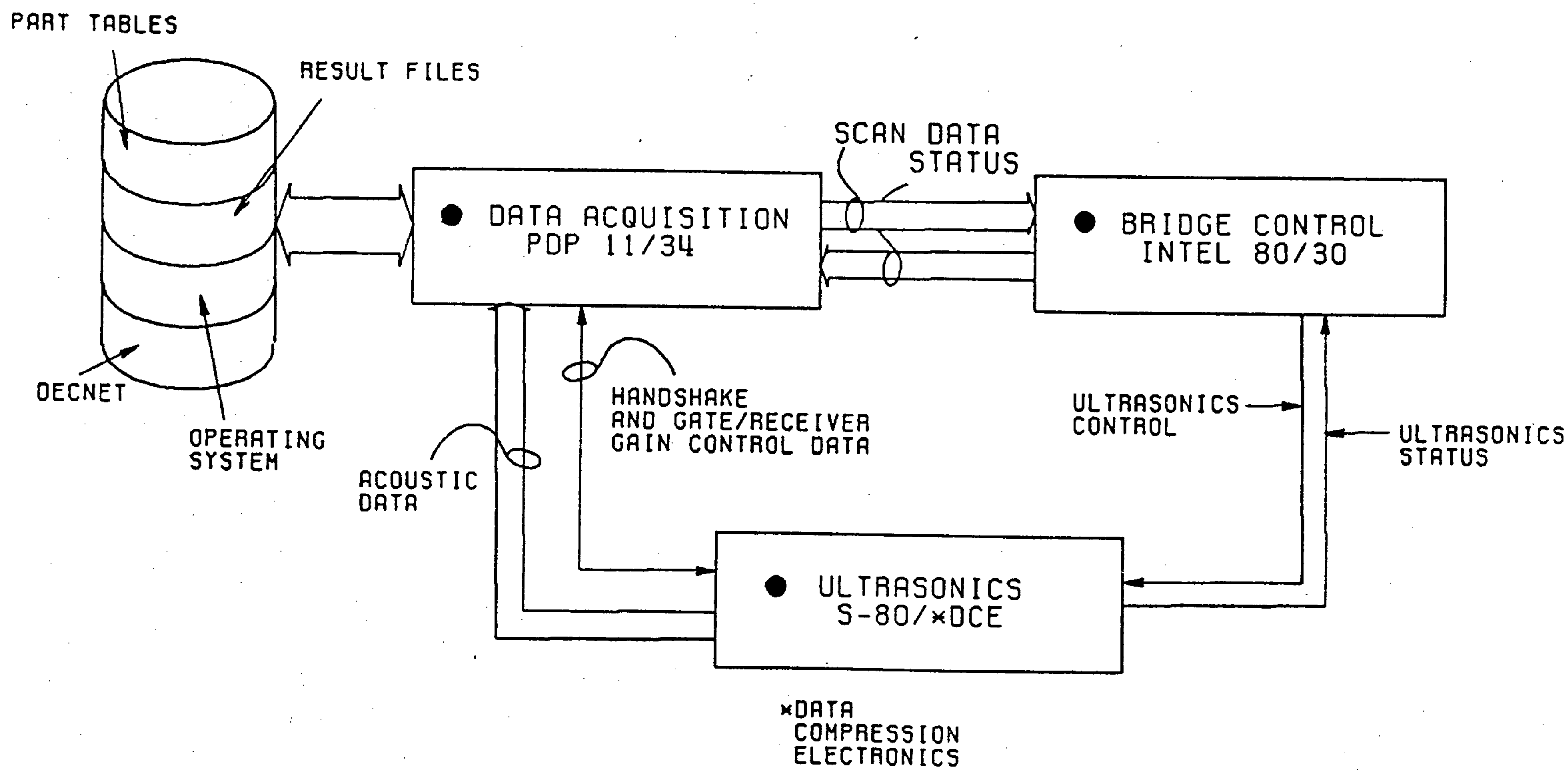


Figure 32 Data Flow/Software Relationship

PLOT - The plotting software module develops a hard-copy plot on either a 72" Versatec plotter or the smaller Printronix printer/plotter.

Each module is depicted in Figure 33.

The major operating module, SCIM, consists of a series of "overlays" that allow the CAUIS operator to run various operations ranging from system initialization to termination of the inspection. For each operation, control is passed from the root segment of SCIM to the appropriate overlay. The following is a brief description of each overlay within SCIM.

Initialize - This operation performs initialization of the SCAN control modules (data initialization, file open, etc.)

Scan Part - This overlay sets up the acquisition system and the bridge controller with specific ultrasonic inspection parameters. These parameters include SCAN coordinates, part definition, inspection options, and ultrasonic instrument set-up data (remote gate settings). This particular overlay spawns the ACQ software modules.

Scan Reference Panel - This overlay operation is similar to the SCAN part overlay function, but is used to verify the ultrasonics set-up with a reference panel. This overlay also spawns the SCAN software module.

Transmit to NET - This overlay invokes the transmission of inspection data result files to the NET system via a DECNET network communication link.

Delete Result File - This overlay deletes a previously captured inspection data result file from the CAUIS.

Define Part, Copy Part Definition, Rename Part Definition, and Delete Part Definitions - These functions are used to enter appropriate part parameters into the part table. The part table is a random access data file containing part information. Each entry in the part table consists of part identification data, remote gate setup information, and part outline coordinates. They are primarily used in first-time part setup and inspection. Subsequent part inspections require only a reference to a previously entered part definition.

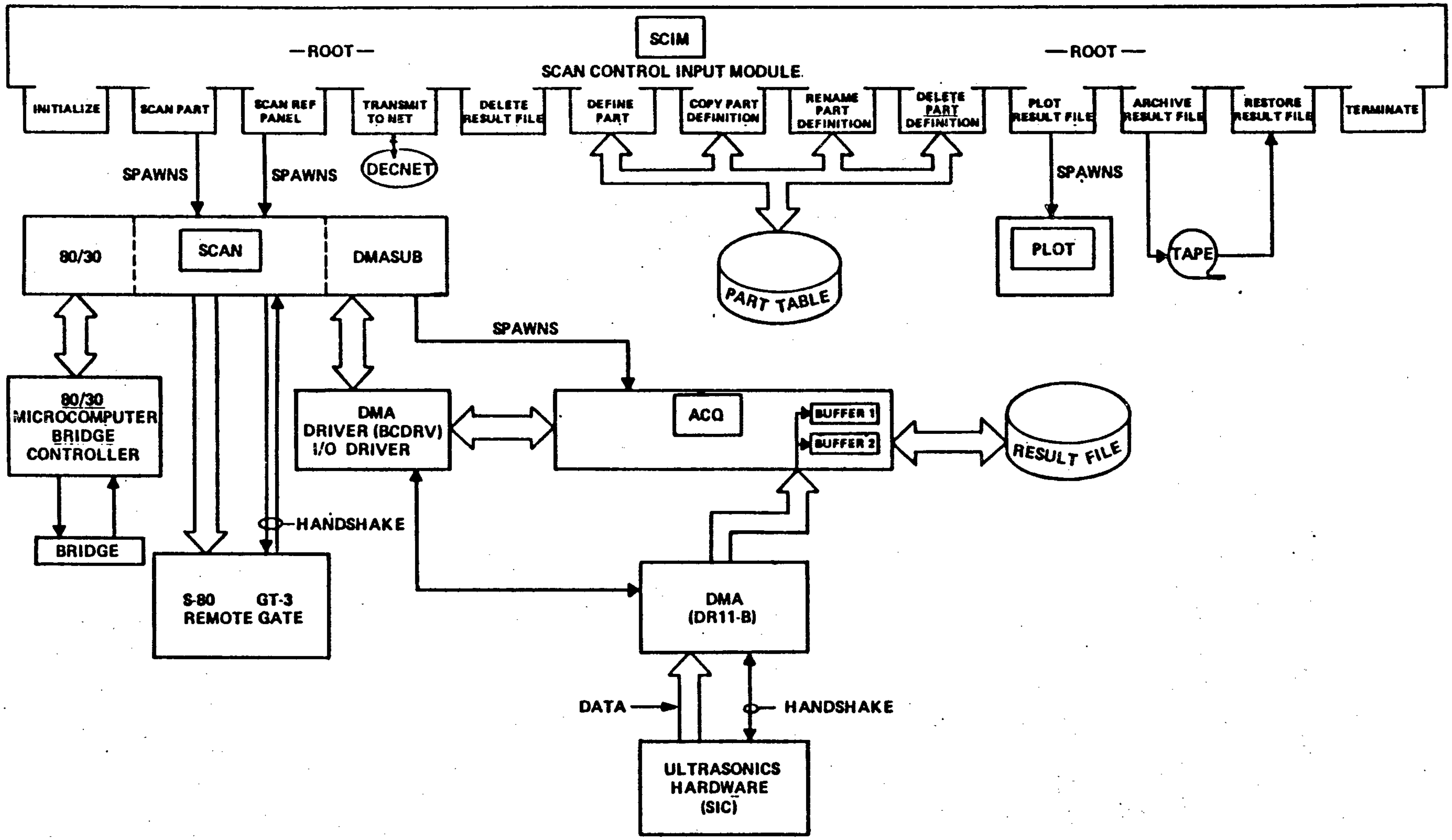


Figure 33 Immersion System Software

Plot Result File - This overlay spawns the local plotting function at the CAUIS. Plotting is accomplished with a 72" Versatec plotter for full or half-size plots. Approximate-scale plots are available from the Printronix printer/plotter. Plotting is displayed in multishade gray-scale. Eight shades, black to white, are currently implemented with the CAUIS in a C-scan format.

Archive Result File - These overlays transfer the inspection-result files from disk to magnetic tape and back as needed.

The SCAN software module is comprised of routines that set up SCAN and inspection parameters to the bridge control Intel SBC 80/30 microcomputer, the S-80 Reflectoscope, GT-3 remote gate, and communication channels with the Direct Memory Access (DMA) function. DMASUB, a subroutine within SCAN, spawns the acquisition subtask. Figure 34 illustrates this organization.

The ACQ, or acquisition software module, performs the memory buffer rotation, Direct Memory Access (DMA) data formatting, and transfer to the RK-07 disk. DMA is a straightforward function receiving ultrasonics data; i.e., amplitude, transducer channel, and vector length from the Automation Industries S-80 Reflectoscope and system interface data compression electronics. Buffer rotation is an I/O driver function that alternately switches the two 256-byte memory buffers on-line with the DMA port upon completion of a line scan or a buffer overflow. The buffer rotation function has a 200 microsecond maximum execution interval that limits the data acquisition to that repetition rate. Data acquisition is currently set up for a 275 microsecond interval.

2.3.4 Bridge Control Software

The bridge controller software is also comprised of modules. These modules are written in 8080 microprocessor assembly language for the Intel 8085 CPU-based SBC 80/30 microcomputer. Figure 35 illustrates the structure of the bridge controller software.

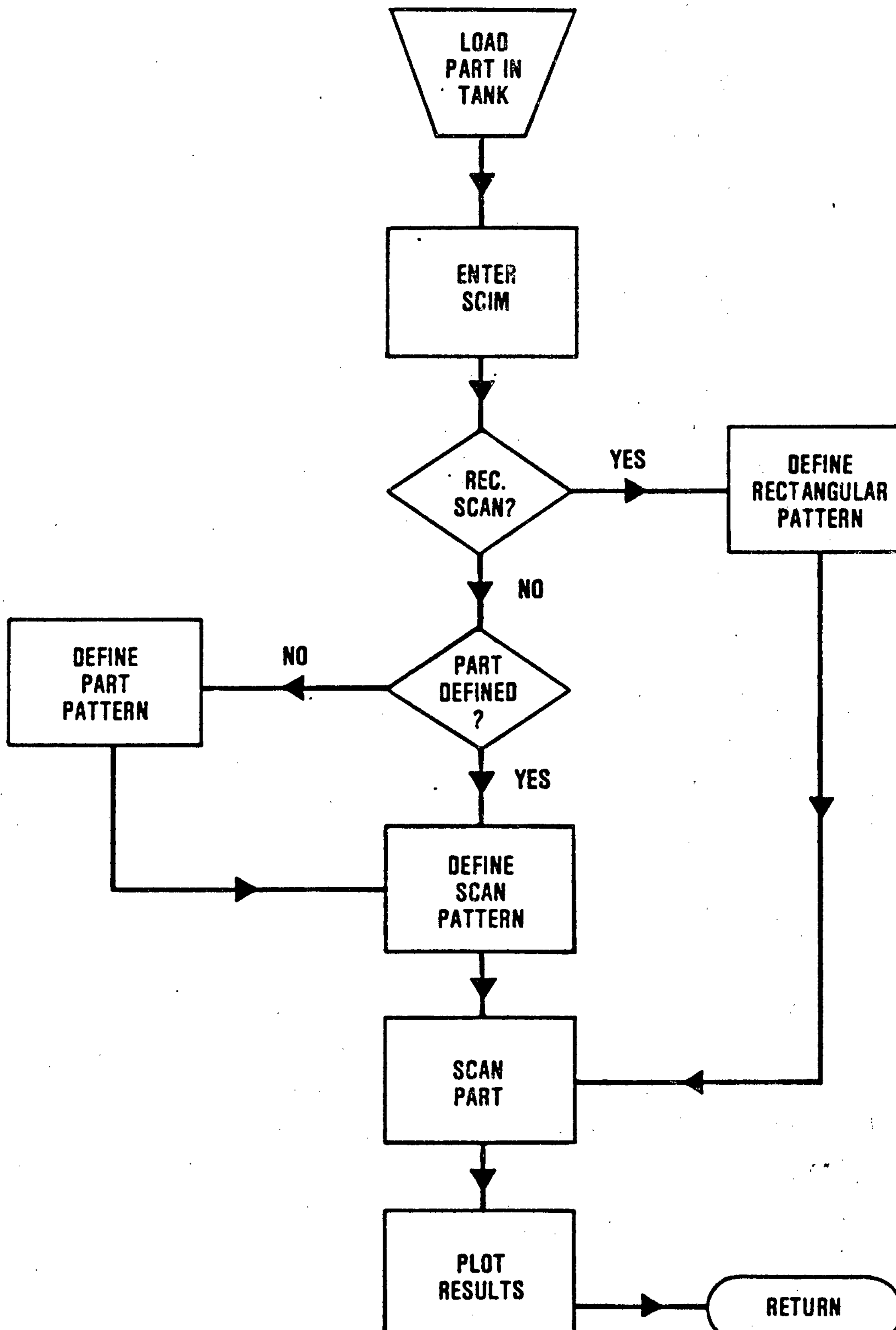


Figure 34 Scan Module

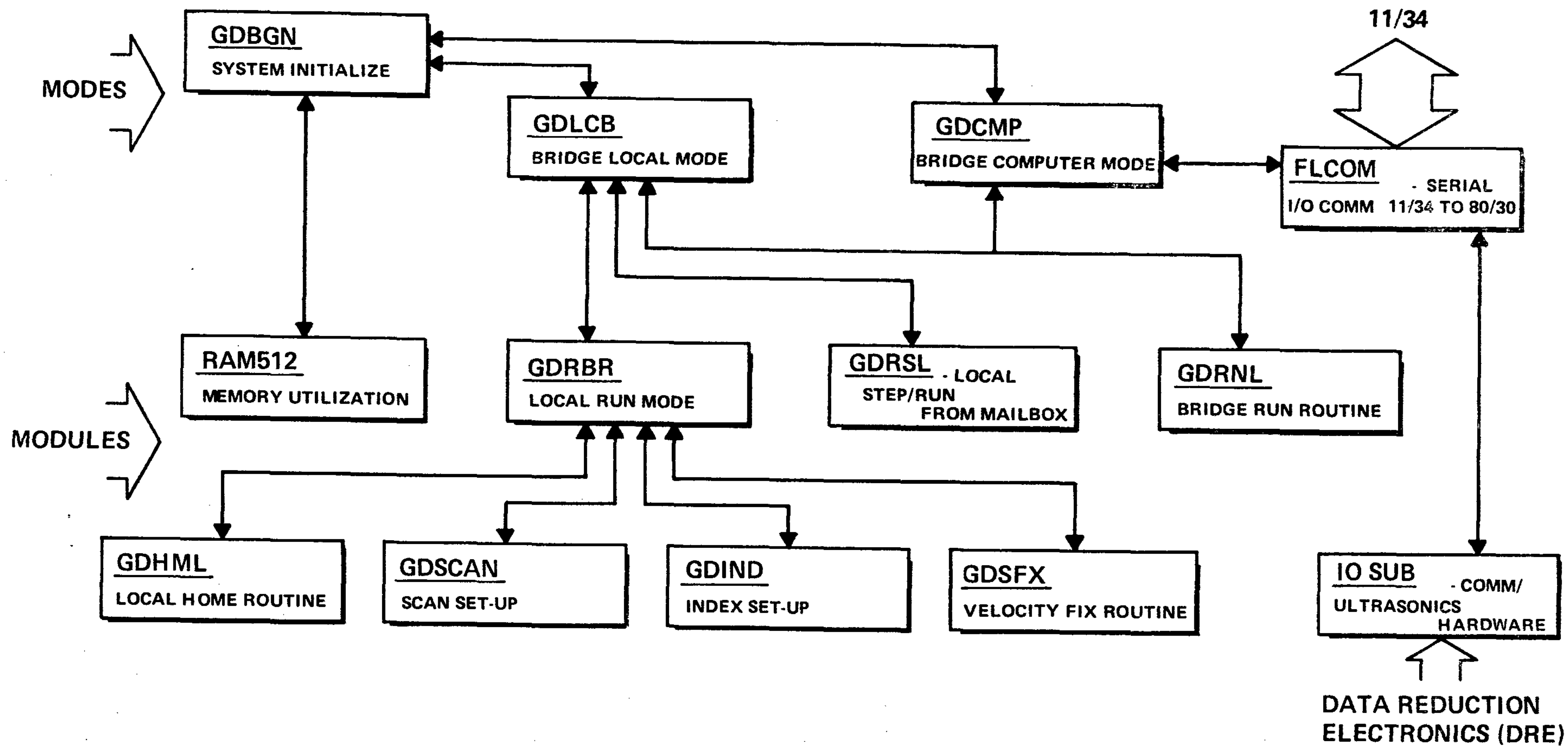


Figure 35 Bridge Controller Software

The GDBGN module performs the system initialization function and also performs many of the operating system functions similar to SCIM in the data acquisition software. The following is a brief description of each software module and its particular function:

INTSUB - Initializes the bridge controller circuitry, resets the mailbox and displays buffer, and sets the timers that monitor the status of the front panel switches and the keyboard every 10 milliseconds. From this module, control is passed to GDOD.

GDOD - The Operating and Display routine monitors front panel status and displays appropriate switch settings and axes positions.

GDCMP - Its main routine is to run the bridge from the PDP 11/34. This module prompts the 11/34 to load scan pattern data into the mailbox RAM, then process that data before transferring control to the GDRNL module which actually performs the bridge control functions.

FLCOM - This module handles the serial input and output communications between the SBC 80/30 microcomputer and the PDP 11/34 acquisition system.

IOSUB - The parallel communication routines between the 80/30 and the ultrasonics data compression electronics are performed by this module. These routines include reset, flush vector, DMA enable, single channel mode, lockout, bridge reset, and set-up. It is through this routine that the data compression electronics communicates with the 11/34 data acquisition system.

RAM512 - a 512 byte random access accessory utilization routine.

GDRBR - The local run-to-run routine that functions from front panel settings and runs the bridge to the start of SCAN.

GDHML - The local home routine. The bridge goes to the home position from the front panel command.

GDSCAN - This is the SCAN setup routine. Front panel entries of SCAN coordinates are read and formatted prior to entry into the mailbox.

GDIND - This module indexes the setup routine from front panel data entries to proper formatting into the mailbox.

GDSFX - This module performs the velocity fix routine from front panel settings for scanning speeds.

GDRSL - The local step and run from mailbox routine is handled by this module. Setup data is read through GDLCB.

GDRNL - This module runs the bridge controller via motor controller circuits and position register data. Input parameters come indirectly through GDLCB (local) or GDEMP (computer) modules.

Each of the software modules contains submodules or subroutines that perform the particular microprocessor operations.

3.0 NONDESTRUCTIVE EVALUATION TERMINAL

3.1 Net System Operation

The Nondestructive Evaluation Terminal provides a centralized data collection and management system for a network of CAUIS stations. Under this contract the NET system was integrated with the multiple transducer array immersion CAUIS station. In addition, an Automation Industries squirter-type CAUIS station, Figure 5, was integrated with the NET and additional CAUIS stations will be integrated in the future as they come on-line. The NET system provides sophisticated flaw evaluation capabilities through the use of advanced color computer graphics. The centralized data management system also allows for the generation of periodic Quality Assurance management information reports. Also, statistical analysis of inspection results have been included in the NET using the central data base. This allows monitoring of trends in the manufacturing process and will eventually allow correlation of trends with their cause. This correlation process can identify and help solve problems in manufacturing. It can also identify processing changes which improve the final part quality, thereby allowing eventual optimization of the manufacturing process.

3.1.1 Data Management System

The heart of the NET is the data management system. It controls all data in the system and allows files to become eligible for processing, flaw evaluation, long-term storage (archival) and statistical analysis. Data may enter the NET in the form of inspection results from one of the high speed data links connected to the CAUIS stations. Data may also enter from magnetic tape, either transferred from a CAUIS or as a recall from archives for further evaluation. Inspection results exit NET onto magnetic tape for long term storage. Inspection results may, in unusual circumstances, be temporarily transferred from disk storage to mag tape. However, in this case, the data management system still maintains control of the inspection results by considering the temporary mag tape storage as simply another location where inspection results are stored. Thus, the data management system is almost unlimited as to the data volume that it can handle.

The NET also creates two other types of data files from the inspection results. During the evaluation process, a hard copy C-scan output may be requested. In this case, NET generates a special data file suitable for output to the Versatec printer/plotter. The results of statistical analysis and Quality Assurance report generation also produce files for printer/plotter output. These files exit the system when they are finally output as hard copy.

The second type of data file produced from the inspection results in a highly compressed version of the inspection results that retains only flaw characterization information significant to statistical analysis processing. This type of data is required because the sheer volume of raw inspection result data is not traceable for the statistical analysis presently planned. These compressed data files will generally be maintained on the system only until they can be conveniently dumped to mag tape for long term storage. When statistical analysis is requested, the tapes containing information on the period that the analysis covers will be mounted and the data reloaded into the system long enough to perform the analysis. When the analysis is complete, the compressed data files will be purged from the system disks.

The data management system controls all of the system data through a set of queues. A queue is simply a list of files with each entry in the list carrying information on the location of the file (disk address or temporary mag tape number), priority, and status. Each queue has some attributes associated with it which all of the entries in the queue share. For example, the print/plot queue is a list of files which share the common attribute that each file is awaiting disposition to one of the system printer/plotters. Data flow is accomplished by moving queue entries from one queue to another at the completion of some processing activity. A complete description of the queues, their attributes, and entry-exit criteria is contained in the NET Computer Software Technical Description which has been published as a separate report.

3.1.2 Inspection Results Evaluation

The inspection result evaluation software will be dedicated to displaying inspection results on the Genisco 3000 Color Graphics Terminal. The inspection

result evaluation software is centered around the use of color to display a third dimension of information rather than resorting to the limited capability of bistate displays or the far more complex and often difficult to interpret 3-dimensional isometric displays of 3-D data. The inspection results for composite skin panels may generally be characterized by an ultrasonic signal amplitude parameter or depth information (or both) at each spatial lattice point on the part surface. Consequently, the display software was designed to display amplitude or depth information as color variations versus the X and Y part coordinates. These displays are similar to a conventional C-scan except that color variations are used instead of the conventional presence/absence of a pen trace.

The inspection result evaluation software is capable of displaying an entire composite skin panel on the terminal at one time. This allows for quick examination to identify potential problem areas. The inspector must then be able to enlarge any given area of a part up to full scale for detailed evaluation. The inspector is allowed to select any desired scale factor at a given location on the part there by filling the display with the inspection results at and near the central location. The inspector can identify a rectangular area on the part for detailed evaluation, and the scale factor will be automatically adjusted to display the area specified such that it just fills the graphics terminal screen.

The inspector can specify either an amplitude or a depth information display. Normally, amplitude will be selected initially, followed by examining the depth information at anomalous areas. For either display, the inspector can specify a set of thresholds which will be used to determine the color associated with the specified ranges of amplitudes or depths. Seven colors corresponding to the specified ranges of amplitude or depth are allowed at one time. (An eighth color is used for background.) Human factors studies indicate that the human eye begins to experience difficulty in differentiating among more than about 8 different colors or shades of gray. If unsure about the results with the thresholds (ranges) selected or if more detail is required for proper evaluation, the inspector may adjust the thresholds in real time on the Genisco screen. Note that if the inspector selects only one threshold (one

color and background), the display will be a conventional C-scan. Finally, the NET will automatically fill in the area between the lines of the conventional C-scan type of display. This leads to a computer enhanced display allowing easier evaluation of inspection results.

The NET is capable of producing a C-scan type hard copy of the inspection results. This hard copy will be triggered by an inspector input from inspection result evaluation software. When the inspector is satisfied that all evaluation parameters are set correctly, he may request a hard copy. Any plot scale factor may be entered; however, lacking an input, a full size hard copy is assumed. The color information on the graphic terminal is transformed into a synthetic eight-level gray scale on the hard copy, thus allowing retention of the amplitude and depth information. The evaluation parameters and other key information, such as serial/part number, inspector ID, accept/reject disposition, will be annotated on the hard copy with a key to the gray scale markings. Enhancement of the C-scan is provided automatically.

3.1.3 Summary Quality Assurance Reports

The Quality Assurance report generation function of NET will be accomplished by extracting information on part and serial number, inspection date, disposition, inspection station, and potential rejection cause from each inspection result file as it leaves the NET for long term storage. This data will be collected for each CAUIS station. The resulting data will be saved and then output at regular intervals in the form of the Quality Assurance management report. The report will be generated by sorting the QA report data collected and cataloging it into a special report form. As an option, the QA engineer may request that a listing of serial numbers be included, instead of merely listing total quantities inspected.

3.1.4 Statistical Analysis Capability

Because of the massive volumes of inspection result data that must be processed by the NET, successful statistical analysis in a reasonable amount of time requires that the data volume used in statistical analyses be significantly reduced. To accomplish this,

some consideration had to be given to the goals and ultimate use of statistical analysis results. Statistical analysis is only useful to the manufacturing process when it can detect trends in the manufacturing process that indicate declining or improving part quality and corresponding changes in manufacturing costs. With this in mind, it became apparent that the raw inspection results should not be analyzed, but rather results processed to reflect only flaws. That is bistate data (flaw present or absent) could be used for statistical analysis equally effectively as the raw inspection results. However, care must be taken to avoid overlooking the impact of flaw depth on the decision to categorize a given anomaly as flaw present or flaw absent. Further, as certain problems (such as porosity) currently appear to be more prevalent in thick laminates than in thin ones, flaw depth must be retained as a statistically significant parameter. Hence, for generating a statistical analysis data base, the raw inspection results will be reduced to bistate (flaw present or absent) data but with flaw depth information retained. This allows separate analysis of flaws at different depths or different ranges of depth.

Accept/reject criteria are currently specified in terms of dimensions of the major axes of the flaw. This suggests that for the purposes of statistical analysis, the flaw could be considered an ellipse with major and minor axis dimensions. For locations on the part in which porosity is evident, flaw area is the governing accept/reject criterion.

Hence, no loss in accuracy would result if all contiguous locations of a flaw at a particular depth were grouped together and characterized by flaw location, depth, major and minor axes, and flaw area. This data reduction system is used for generation of the statistical analysis data base for each part inspected in the factory CAUIS network. This data reduction system is used for generation of the statistical analysis data base for each part inspected in the factory CAUIS network. This data reduction technique is applied to all inspection result files as they leave the NET for long term storage. A separate statistical analysis data base will thus be generated, specifically for subsequent statistical analysis processing.

Statistical analysis may be requested by a Quality Assurance engineer. The engineer must specify part number and time or serial number interval over which the analysis is to take place. For analyses in which time

or serial number is an independent variable, the engineer must also specify an "averaging window." This feature allows selectable smoothing of trend characteristics. The engineer will also be able to specify the area of the part and the range of depth values to be included in the analysis.

The NET is capable of calculating a flaw density function estimate at each coordinate of the part. This density information may be displayed as color on the Genisco 3000 Color Graphics Terminal or as a gray scale on the Versatec printer/plotter. Ranges of density encoded into color may be specified as in inspection result evaluation. Note that specifying only one range would result in a composite C-scan, showing all flaws over the part sample specified. Specifying several ranges would display areas of the part on which flaws occurred in the specified percentage range. This function is expected to provide the maximum flexibility in statistical analysis capabilities as it allows generation of a great amount of information by varying a few parameters.

The NET can also generate a flaw depth density function, displaying relative occurrence of flaws as a function of depth. As usual this analysis may be specified over a given sample of part/serial numbers, area and depth. When used judiciously, this capability combined with the flaw density function will provide maximal statistical analysis capabilities, and could lead to the eventual establishment of a sampling plan.

NET will also provide some additional (more gross) analysis capabilities. The mean and standard deviation of the number of flaws per part, area of flaws per part, and the ratio of number of flaws per area can be calculated. These calculations can provide management with an indicator of the health of the manufacturing/inspection process.

3.2 Nondestructive Evaluation Terminal Hardware

The Nondestructive Evaluation Terminal (NET) provides a centralized data collection and management system for a network of CAUIS stations. A block diagram of the hardware portion of the NET system is shown in Figure 36. It consists of a Digital Equipment Corporation (DEC) PDP-11/60, shown in Figure 37 with 256 kilobytes of memory. The system was selected to provide a modular design with maximum flexiblity and growth capability. The system is reliable with excellent

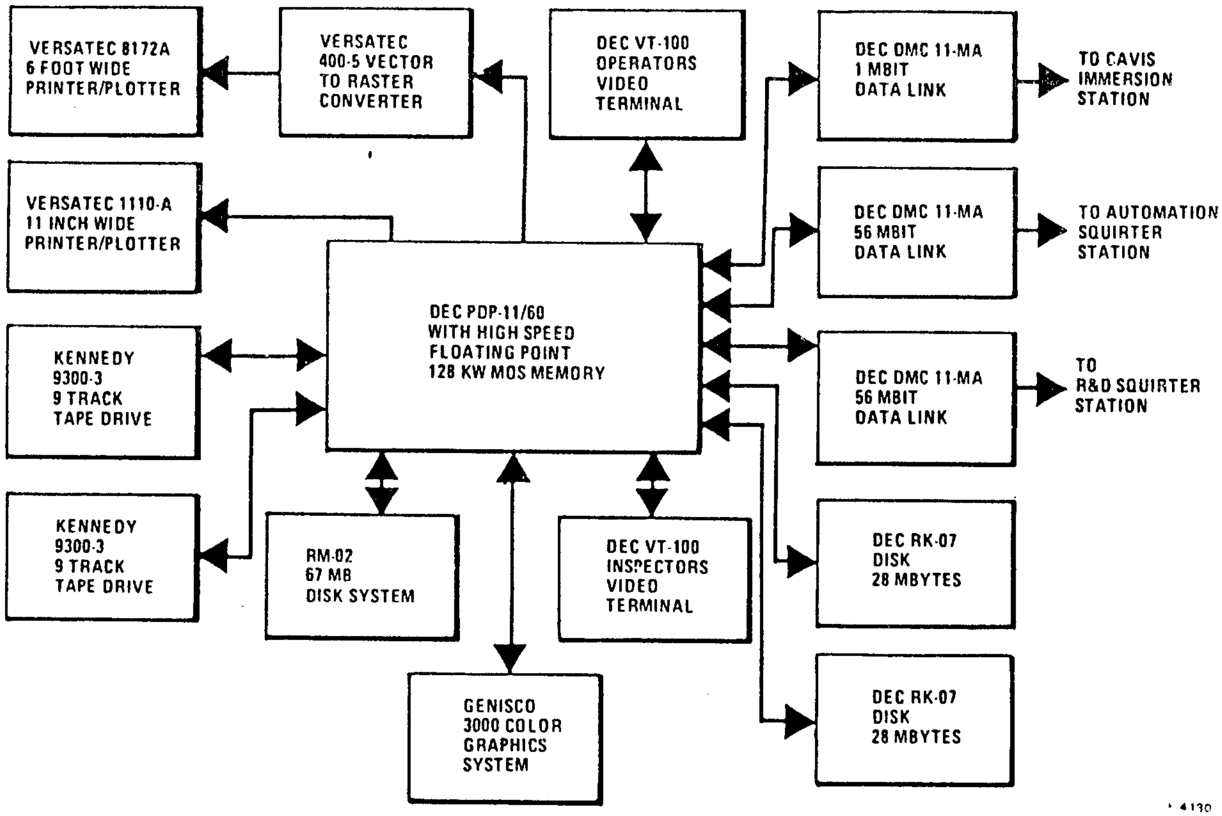


Figure 36 Nondestructive Evaluation Terminal Hardware

vendor field service available when required. This system is also compatible with the PDP-11 series computers used at the individual CAUIS stations.

Two DEC RK-07 disk drives, shown in Figure 38 (28 Megabytes each) and one RM-02 disk drive (67 Megabytes) were selected to meet the disk storage requirements.

The RK-07 drive numbered 0/ is used for the system drive. The other RK-07 is used for storage of statistical analysis files. The RM-02 is used for the storage of inspection results.

The NET system uses two Kennedy 9300 nine-track magnetic tape drives, previously shown in Figure 37 for long term storage of inspection results and to provide alternate means of transferring data between CAUIS stations and the NET. Two drives are needed to produce backups and to allow operations such as simultaneous long term storage of inspection results and cataloging of statistical analysis data.

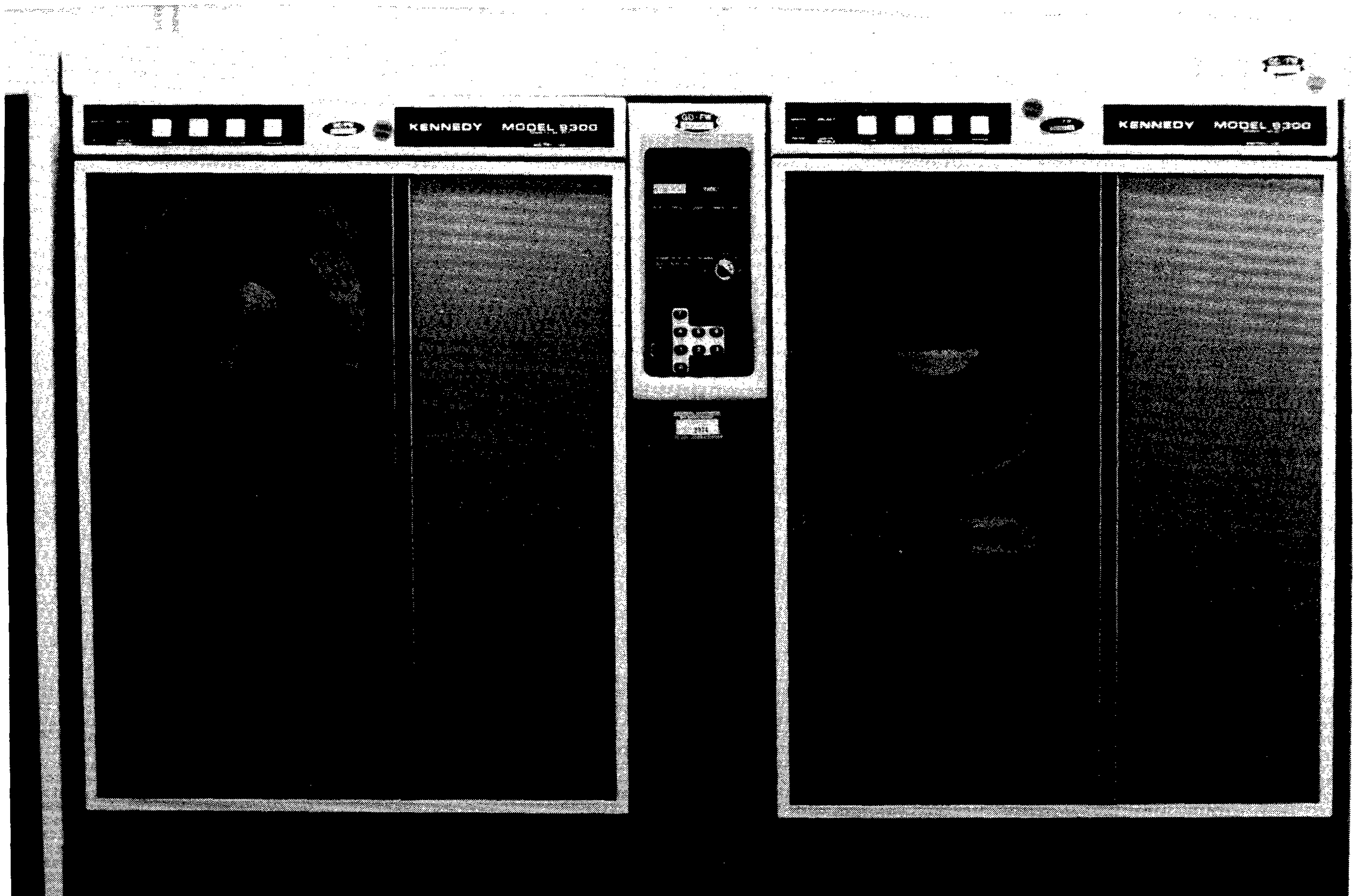


Figure 37 Digital Equipment Corporation (DEC) PDP 11/60

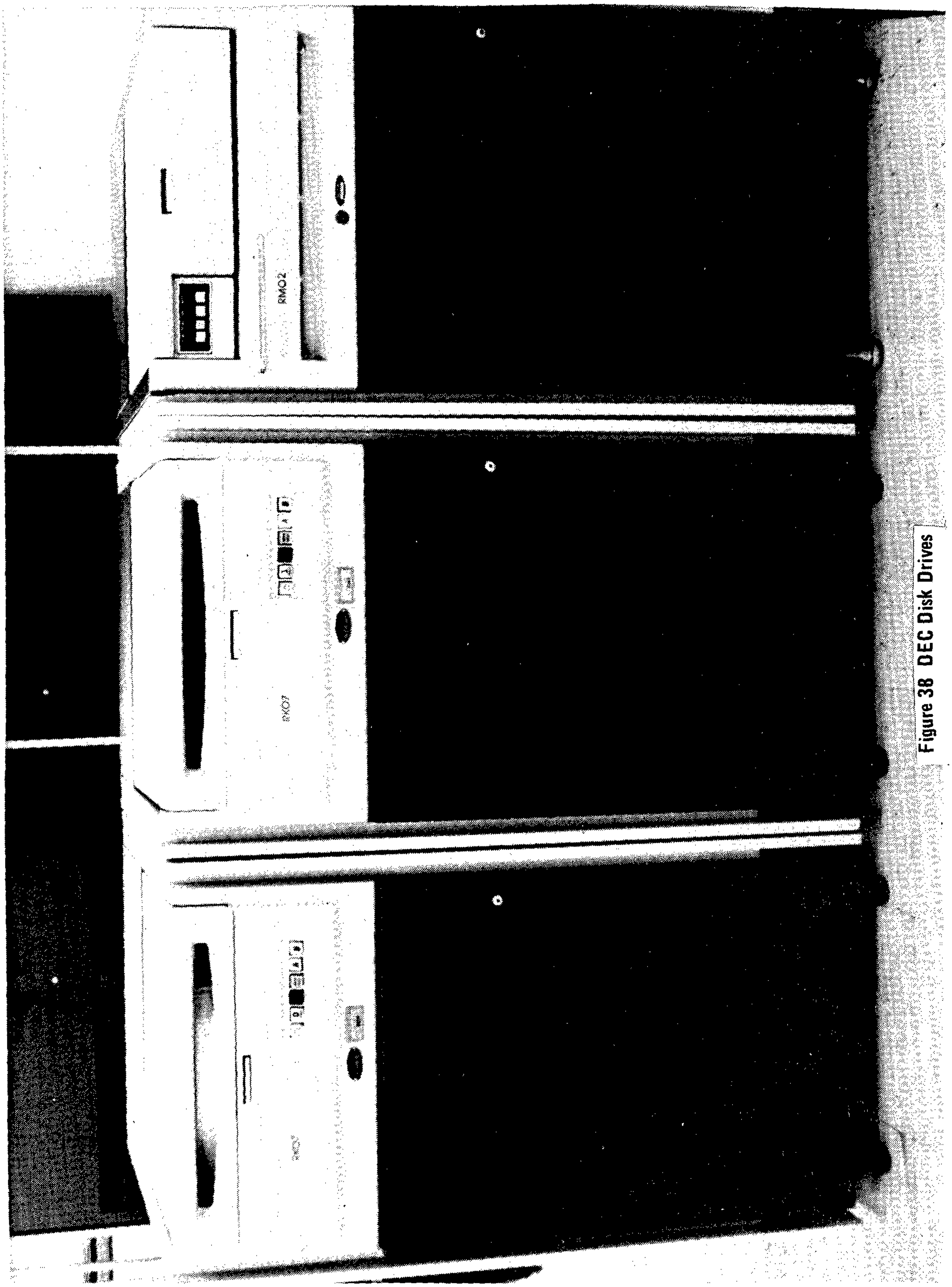


Figure 38 DEC Disk Drives

The color display of inspection part files is being handled by a Genisco 3000 graphics processor, Figure 39. This system has several factors that make it well suited for use in the NET computer system. The Genisco system has a custom CPU (Central Processing Unit) which has a processing rate much faster than the speed of most off-the-shelf microcomputer CPU's. This speed is aided by the fact that the Genisco is a DMA device. This means the Genisco interface resides in the DEC-11/60 computer backplane and can access DEC memory directly with the same speed as a disk drive or other high speed devices. Being a DMA device will allow the Genisco to present graphics inspection data many times faster than is possible with a serial type graphics terminal. In addition, the Genisco has its own CPU memory where programs can be loaded to act upon data sent to the Genisco from the DEC 11/60. This feature will allow the Genisco to pick up part of the computational load from the DEC-11/60. This feature is of utmost importance in the effort to keep the graphics displays as interactive as possible.

A DEC VT-100 CRT terminal, shown in Figure 40, is used to provide the inspector's interface. The menu drivers and input drivers for the Genisco graphics system are on the inspector's VT-100, leaving the Genisco system dedicated to the graphics displays.

The second VT-100 serves as the NET control terminal to provide centralized control over all data management functions, automatic processing operations (such as the data link, Versaplot, or mag tape operations), Quality Assurance report generation, and statistical analysis operations. This terminal has protected/unprotected field definition capabilities, addressable cursor positioning, and tab functions. This will greatly simplify operator interface with the system and minimize operator inputs. By addressing these human factors, the system does not require a highly skilled computer operator. A typical inspector or Quality Assurance engineer will be able to successfully exercise all of NET's capabilities and functions with a minimum of training.

A DEC LA36 (DECWRITER), Figure 41, serves as the system message logger. The DECWRITER is also the system console. The DECWRITER is the only device with the capability to address the DEC operating system.

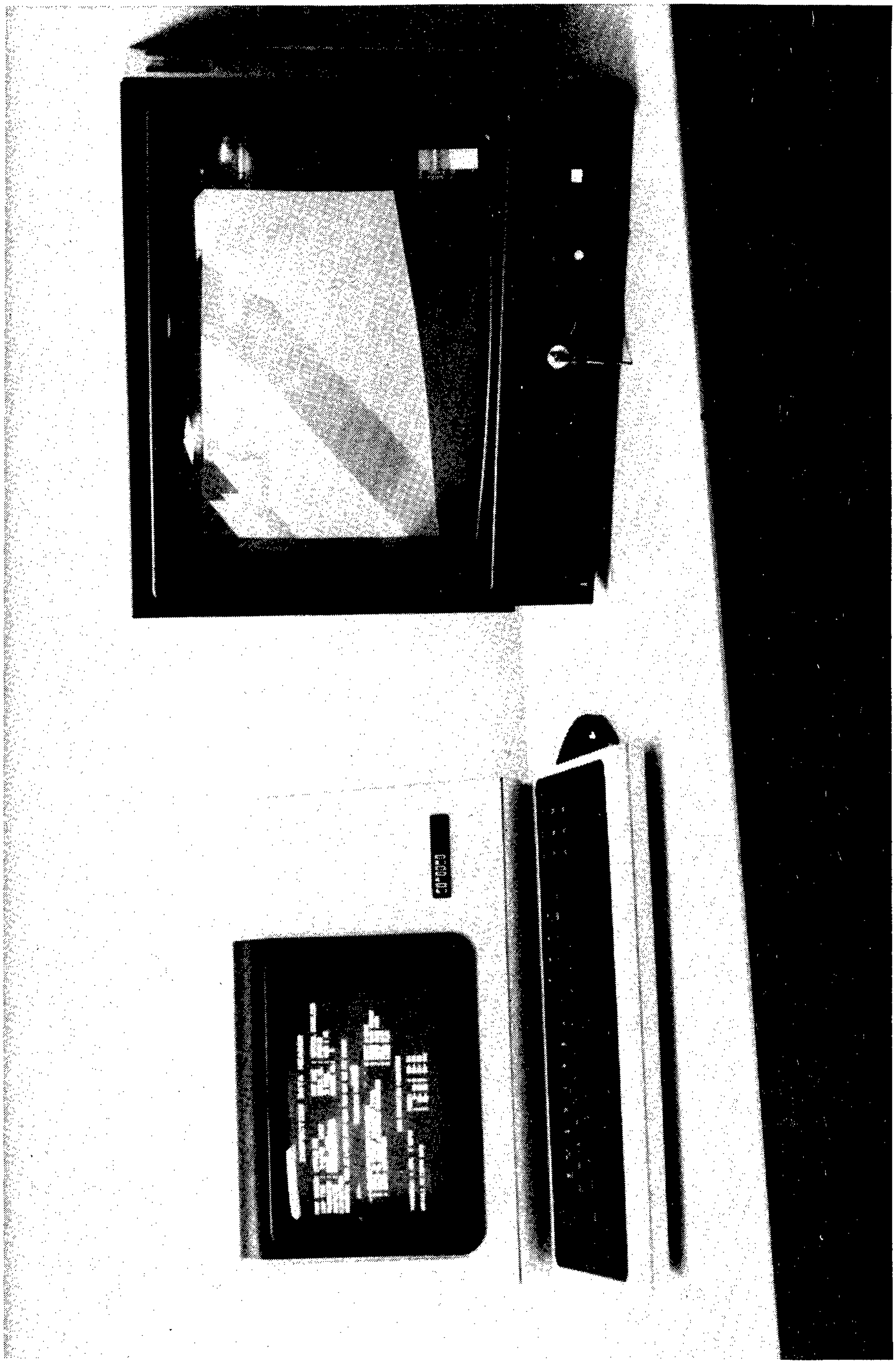


Figure 39 Genisco 3000 Graphics Processor

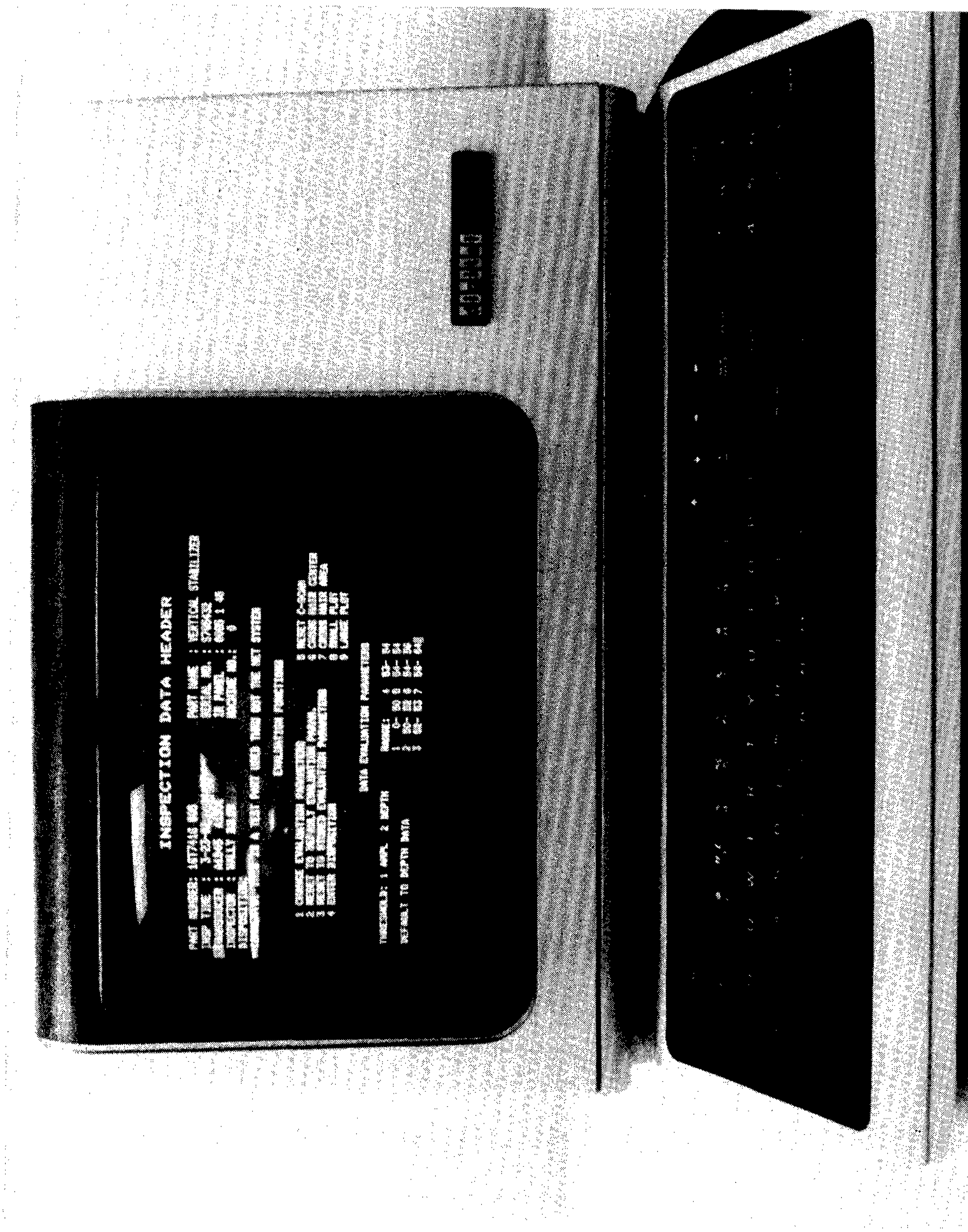


Figure 40 DEC VT-100 CRT Terminal

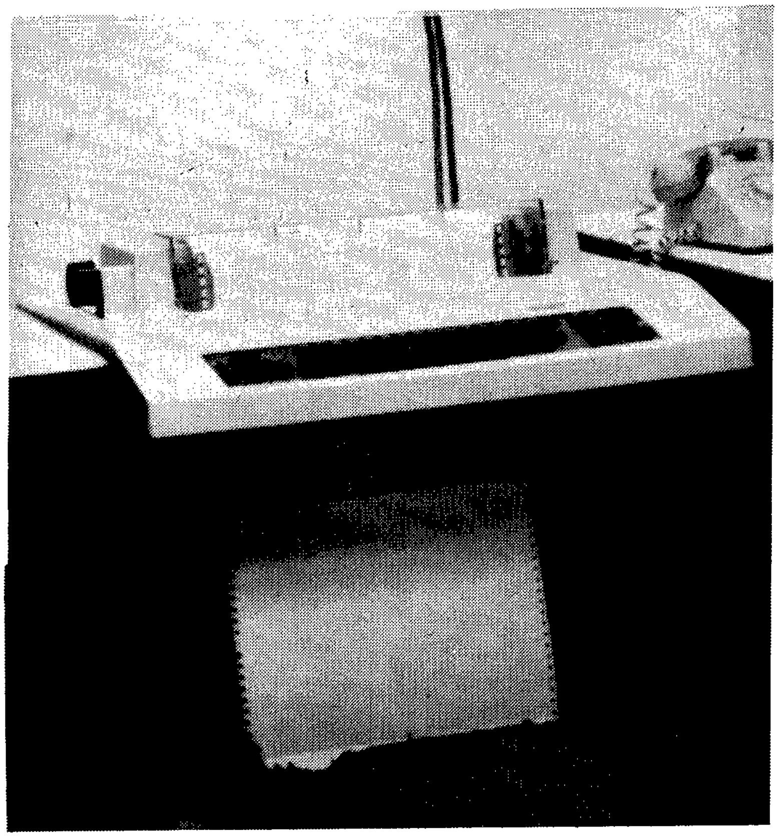


Figure 41 DEC LA36 Decwriter System Console

Full flaw evaluation capability occasionally demands a full-size C-scan of the inspection results. It is always required in the event of a rejection. A Versatec 8172A 6-foot printer/plotter fulfills this demand, Figure 42. This is the only known computer-interfaced production plotter system which will meet the demands for high speed C-scan generation. Some large bed pen plotters are available; however, these devices are not able to generate a full-size C-scan in less than 15 to 20 minutes. They do not have automatic paper positioning capability, thus requiring additional time for the operator to load and position the paper sheet for each C-scan produced. In addition, the mechanical movements of these devices would likely lead to excessive downtime. The Versatec 8172A is a raster oriented device, therefore possessing inherent capabilities to produce synthetic gray shading. This feature allows color information available on the main graphics display to be transformed to a synthetic gray scale and reproduced as a hard copy.

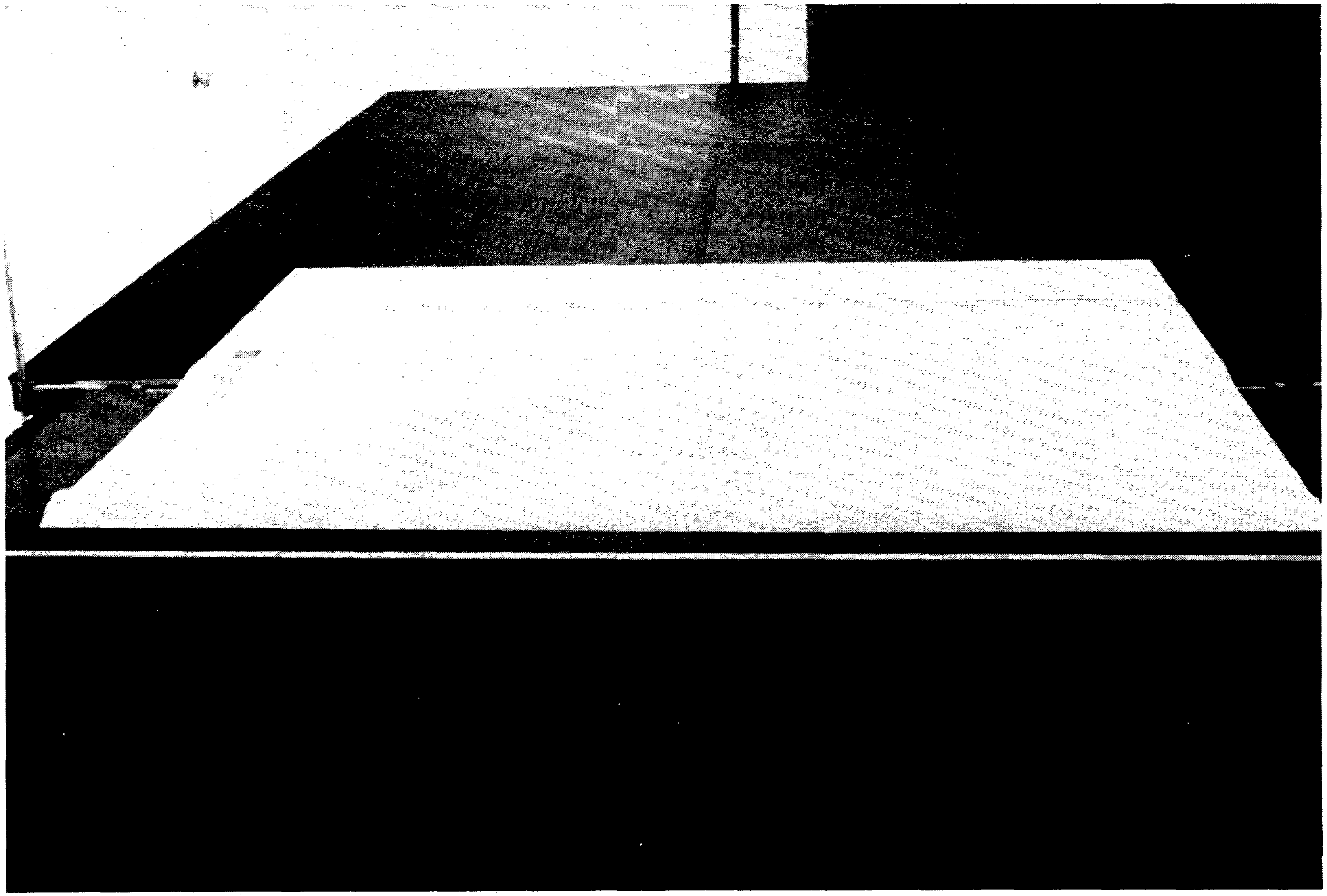


Figure 42 Versatec 8172A 6-Foot Plotter

The NET system also uses a Versatec 400-S Vector-to Raster converter, Figure 43, to assist in the raster file conversion. The hardware vector to raster converter will aid the plotting process by taking the vector file produced by the Versaplot software and producing the raster conversion in hardware therefore increasing the Versatec plot speed.

A Versatec 1110-A printer/plotter, Figure 44, serves as an output device for producing the Quality Assurance management information system reports and publishing the results of statistical analysis of the inspection data. The Versatec 1110-A is an 11-inch wide printer/plotter and has the advantage of having common software with the 8172A plotter, allowing for common software development.

A hardware floating-point math unit is included with the system to allow more rapid statistical analysis and plotting of inspection results. Statistical analysis and plotting is generally intensive with floating-point multiply/divide calculations, which are very time consuming when accomplished by software. However, when these calculations are off-loaded to a special hardware unit, a processing speed improvement of close to an order of magnitude can be achieved. In addition, the hardware floating-point math unit is also needed for software development whenever the optimizing Fortran compiler is used.

To transfer inspection results from the CAUIS station to the NET, a DEC DMC-11 data link package is used. This is a very high-speed link (1 Mbit/sec) designed specifically to link PDP-11 series computers. The 1 Mbit/sec rate was selected to allow timely handling and transmission of inspection results (in real time if needed) resulting from the time-multiplexed array. In addition, a special software package was purchased from DEC to control data link operation. The DEC link control software greatly reduced the software development effort required to integrate data links into the CAUIS-NET factory inspection system network.

The Nondestructive Evaluation Terminal hardware configuration has been guided by the need to minimize software development efforts and data processing time. Since the NET will be handling tremendous volumes of data, rapid processing is critical to production implementation success. The resulting configuration provides the ultimate processing speed achievable. No shortcuts or compromises have been allowed in this hardware configuration.

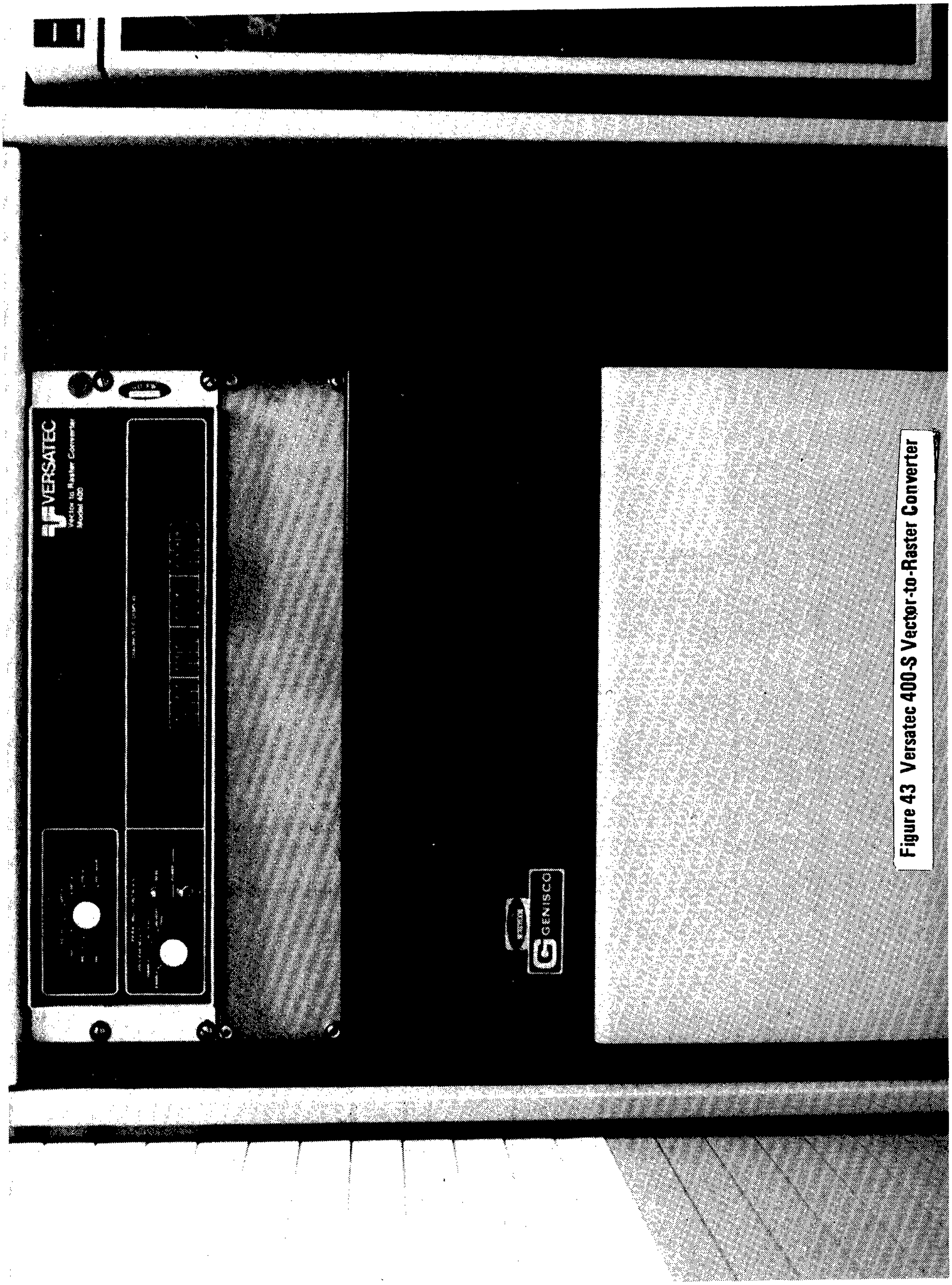


Figure 43 Versatec 400-S Vector-to-Raster Converter

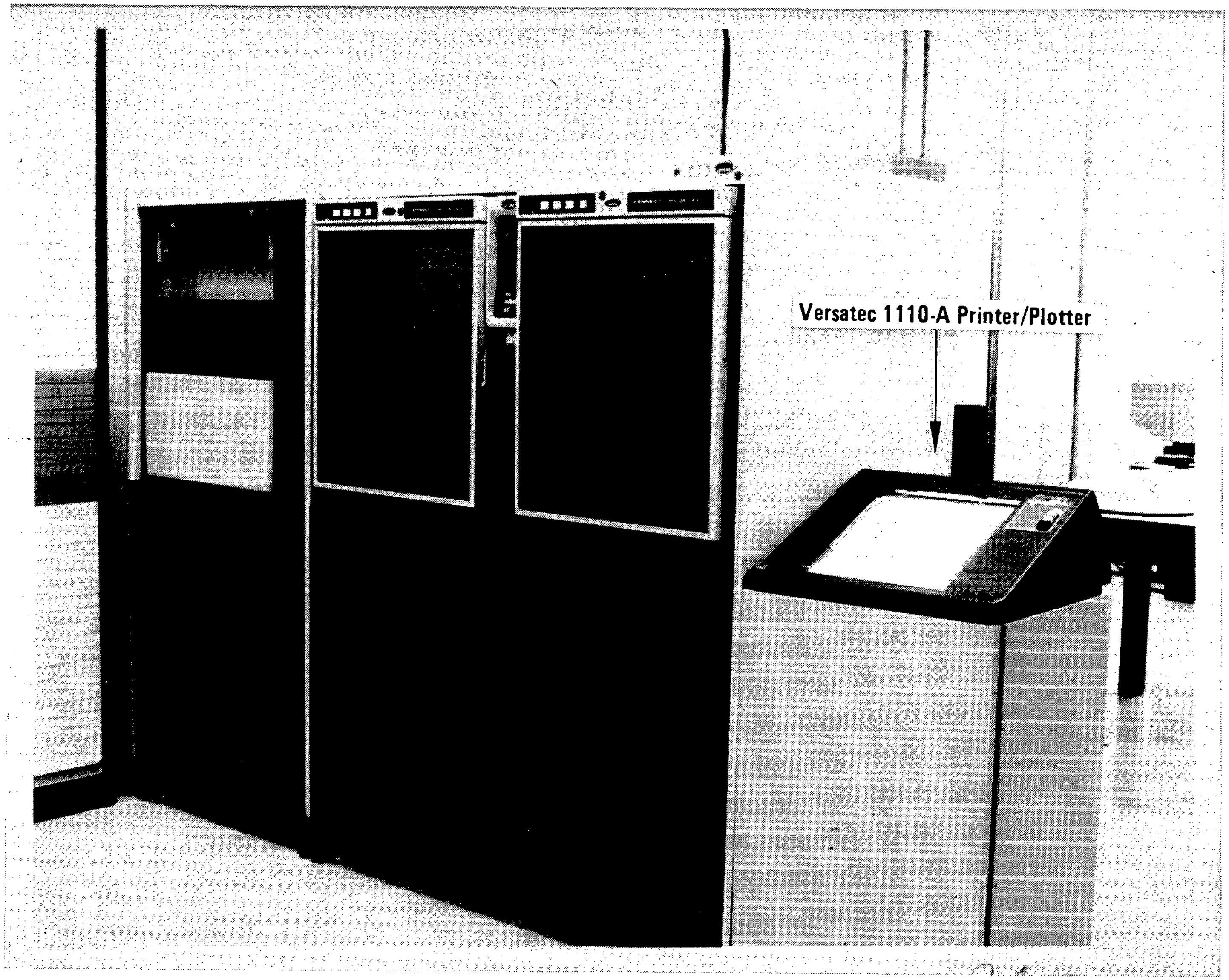


Figure 44 Versatec 1110-A Printer/Plotter

3.3 Nondestructive Evaluation Terminal Vendor Supplied Software

Software development for the NET system began with the selection of basic off the shelf system software to be used as the backbone for the NET application programs.

Software packages used by the NET system are:

- RSX-11M DEC PDP-11 multitasking operating system
- Fortran IV Plus optimizing Fortran compiler
- DEC NET Phase III data link management system
- Versaplot - Plotter routines designed specifically for Versatec printer/plotters.
- Genisco executive used to load micro instructions into Genisco color graphics system.

3.4 Nondestructive Evaluation Terminal Application Software

Control of the NET system is accomplished via menus on which the operator selects an operation or task from a list of options, Figure 45. When an operation is selected, one of two displays appears - either a new menu requesting more detailed information or tabular information for editing purposes, Figure 46. After all options have been displayed, or after the operator indicates that editing has been completed, a request for the specified operation is entered in the appropriate queue, and the master menu is displayed. At any time, the operator may cancel an incomplete operation request.

As a result of this design philosophy, the NET functional specification is segmented into areas which provide detailed information concerning various queues,operations performed on queue entries, and operator interface functions. A block diagram of the

MASTER MENU

OPTIONS: LIBRARIAN

SPOOLER

SYSTEM STATUS

Q. A. REPORTS

SHUTDOWN

FILE BACKUP AND RESTORE

Figure 45 Nondestructive Evaluation Terminal Master Menu

SPOOLER QUEUE 03-NOV-80 14:37

JOB	DEVICE	TYPE	HOLD	KEEP	COPIES	PRI	NAME
456	SMALL	PRINT	READY	DELETE	2	55	QA REPORT
437	SMALL	PRINT	READY	DELETE	2	55	QA REPORT
438	SMALL	PRINT	READY	DELETE	2	55	QA REPORT
398	SMALL	PRINT	READY	DELETE	1	10	STAT REPORT
292	SMALL	PLOT	HOLD	DELETE	1	05	SN 876543
222	LARGE	PLOT	HOLD	DELETE	1	50	SN 123456
278	LARGE	PLOT	HOLD	KEEP	1	20	SN 876543
282	LARGE	PLOT	READY	DELETE	1	20	SN 212121

Figure 46 Typical Queue Listing as Displayed on the Net Operator Terminal

NET system software is shown in Figure 47 and the tasks that make up the NET system are listed below:

- o System Manager tasks
- o Librarian tasks
- o System status
- o Statistical analysis
- o Quality assurance reports
- o Nondestructive inspection program.

A detailed description of these tasks follows.

3.4.1 System Manager

The NET system is comprised of different tasks performing a wide range of functions. Execution of some of these tasks is "time critical". That is, some of the NET functions are performed in a near real-time environment (e.g. operator interface). Other tasks are low priority and/or CPU intensive in nature. They should, optimally, execute on an "as resources are available" basis. Between these two extremes are tasks which must execute on a timely basis, but would not be considered "time critical". Executing all tasks at the proper time and priority is the function of the System Manager.

The System Manager is comprised of five distinct sub-tasks which control all data transfers, data management functions, and task execution priorities and times. These five sub-tasks are as follows:

- o System Initialization
- o Operator Interface
- o Inspection Result Queue Monitor
- o Task Execution/Priority Control
- o System Shutdown

These sub-tasks are detailed in the following sections.

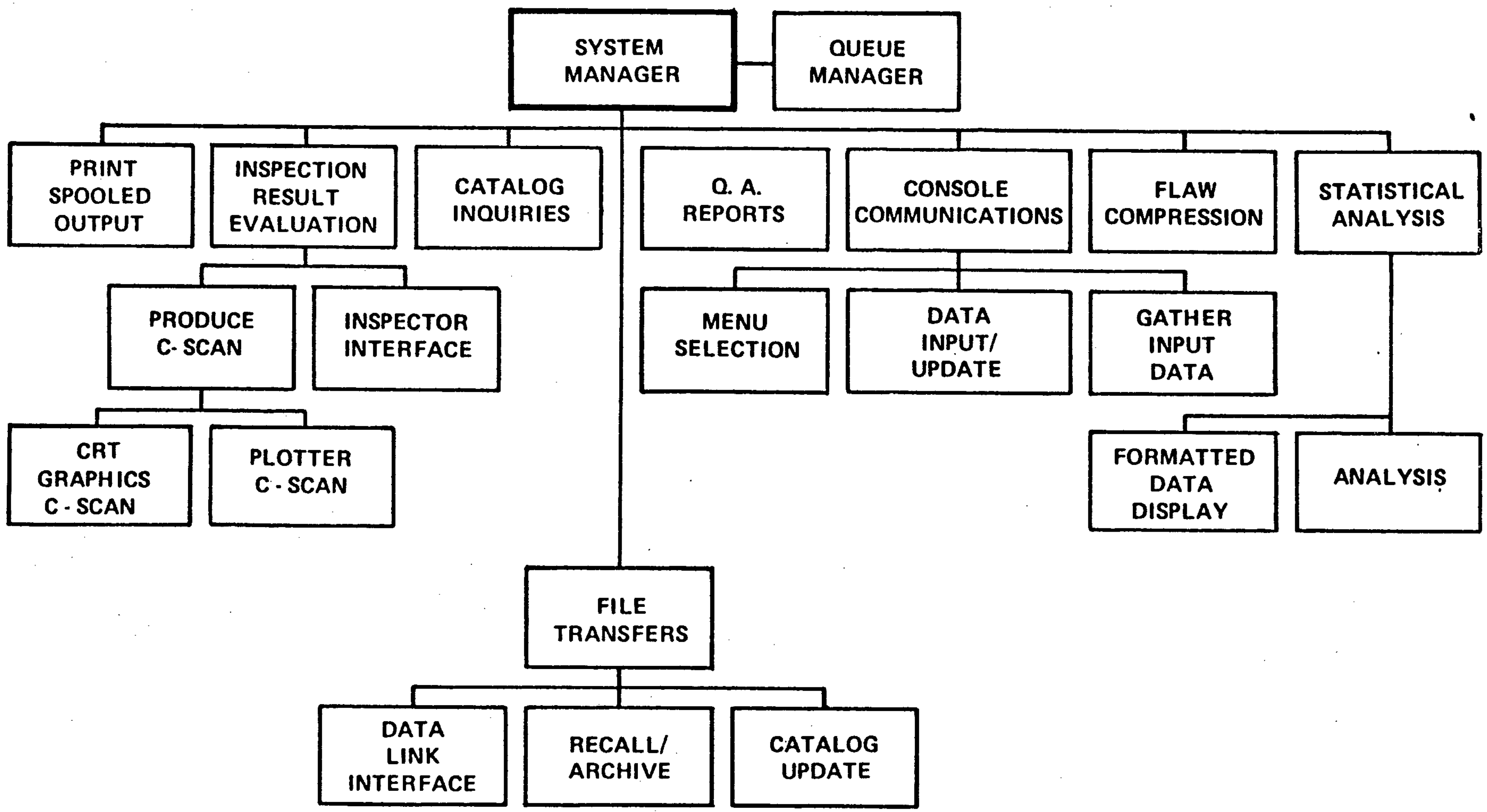


Figure 47 Net Software Structure

3.4.1.1 System Initialization

The correct procedure for initializing the NET system is as follows:

- o Turn on power to computer and all peripherals
- o Wait until all disk drives are ready
- o Depress HALT key on computer front console
- o Depress the CONTROL key and BOOT key together.

The initialization routine takes control of all peripherals and the NET system loads the System Manager in memory, initializes the system control tables with default values, loads all queues from values saved on disk from the last system shutdown, activates the System Manager task, and begins executing at the entry point which causes display of the Master Menu. The System Manager logs the initialization time and status of system on the DECWRITER. The system is now ready to accept commands. All System Manager functions also begin executing. The MASTER MENU display is as shown in Figure 48.

```
                MASTER MENU


        1  LIBRARIAN
        2  SPOOLER
        3  SYSTEM STATUS
        4  STATISTICAL ANALYSIS
        5  Q.A. REPORTS
        6  SYSTEM SHUTDOWN
        7  CAUIS MESSAGES
```

Figure 48 Master Menu Display

The operator may select one of the MASTER MENU options by entering the desired option number and depressing the ENTER key. In this case the desired option tasks are loaded and take control of the console menu area. Otherwise, all automatic processing functions continue

uninterrupted.

3.4.1.2 Operator Interface

The Operator Interface subtask controls the three system terminals. Messages from NET system tasks are passed to the System Manager Operator Interface subtask with parameters which define the source, type, and priority of the message, the destination terminal identification, and an address indicating where the text of the message is located. These messages are displayed on the specified console according to message type. Five message types and a set of operation responses are currently defined:

1. Menu Display

This message type is displayed on the console (or color graphic terminal) menu area. The message text contains control characters which define line number (in display area) and the first character position for each line.

2. Operator Input Prompts

This message type consists of text complete with first line number, first character position, and field length for the screen area in which responses will be accepted. This type display is applicable for both the console and color graphics terminal.

3. Error Messages

This message type is an output only message (no operator response is expected). Error messages are normally displayed on the DECWRITER. Error messages will normally be displayed for at least 30 seconds before being replaced by the next highest priority error message. The Operator Interface subtask is solely responsible for achieving this timing criterion. If the error is not corrected, it will be displayed repeatedly.

4. Immediate Operator Response

This message type is reserved for communications with the operator which require a timely or positive response. The operator response may be merely acknowledging the message, or, in some cases, an input of the requested data. In any case, the message is not

replaced by the next highest priority message until a valid operator response is received. The message format is the same as that used for operator input prompts.

5. Tabular Listing of Data

This message type consists of control characters which define fields in the display menu area, followed by the data which fills said fields, correlated by line number. The operator is generally allowed to edit the display and then reenter the data by passing the edited field back to the calling task.

6. Operator Responses

The Operator Interface subtask of the System manager is also responsible for collecting the operator response to system messages. Full editing functions and cursor position control are supplied by the Operator Interface subtask. Only fully edited and properly entered messages will be passed back to NET system tasks. The Operator Interface subtask maintains a table ordered by terminal ID and terminal display area. Whenever an operator response is entered (by depressing the ENTER key), the appropriate data is returned to the NET task requiring the data. This is accomplished by searching the Operator Interface task tables until an entry is found which matches both the terminal ID and the message type (CRT screen area) associated with the operator response. When a match is found, the data is passed to the affected routine and the next highest priority output message (system to operator) is then displayed.

Seven operator response categories are allowed:

- Console menu Display Response - A single numeric character identifying the menu option selected.

- Color graphics Terminal Menu Response - A single numeric character identifying the menu option selected.

- Console Input Prompts - A string of alphanumeric characters received from the menu display area.

- Color Graphics Terminal Input Prompt - A string of alphanumeric characters received from the menu display area.

- Console Immediate Operator Responses - A string of alphanumeric characters recieved from the bottom two lines of the console.

- Console Tabular Data Listing - A table of data received from the menu display area.

- Color Graphic Terminal Tabular Data Listing - a table of data received from the menu display area.

3.4.1.3 Inspection Results Queue Monitor

The system manager maintains a set of queues which are used during the graphics inspection process. The queues are described in the following paragraphs.

1. Evaluation Queue

This queue contains a list of file names of inspection results which require evaluation by the Q. A. inspector. These files have neither been accepted or rejected by any inspector. Once the inspection results have been evaluated, the file is transferred to the Material Review Board Hold Queue or to the Evaluated Inspection Result Queue. Files may enter this queue from a CAUIS station data link or a CAUIS station transfer tape.

2. Special Evaluation Queue

This queue contains raw inspection result files which have been recalled from archive for further evaluation. Entries to the queue may only be made from an archive tape or the Evaluated Inspection Result Queue. When an entry is removed from the queue, it is purged from disk if the file is also maintained on both a primary and backup magnetic tape; otherwise, no other action takes place.

3. Evaluated Inspection Result Queue

This queue holds inspection result files which have been accepted or scrapped, but which still require the statistical analysis and/or Q. A. report data compression processing. Entries to this queue may be transferred from either the Evaluation Queue or the Material Review Board Hold Queue. Entries in this queue may only be deleted when the data compression processing is completed. The entry is then transferred to the Archive Queue.

4. Material Review Board Hold Queue

This queue holds inspection result files which have been evaluated by the inspector and found to be of substandard quality. These inspection result files are held until additional evaluation by the Material Review Board yields a use-as-is, rework, or scrap verdict. In the rare event of a rework requirement, the inspection results are purged from disk without archival. This is acceptable because the reworked part must subsequently undergo a full inspection after rework is completed. The subsequent inspection would then be archived. If the material Review Board yields a use-as-is or scrap verdict, the inspection results are transferred to the Evaluated Inspection Result Queue for normal archival procedures.

5. Archive Queue

This queue holds entries for inspection results which have been fully evaluated and Statistical Analysis and Q. A. report data compression functions completed are ready for archival on magnetic tape. Entries to this queue may only be transferred from the Evaluated Inspection Result Queue. Entries to this queue may only be removed when both a primary and backup magnetic tape have been created.

6. Statistical Analysis Queue

This queue contains entries for statistically compressed inspection results which are required to accomplish a requested statistical analysis procedure. This queue will be empty if no statistical analysis is pending or in-process. Entries are deleted when the requested statistical analysis is completed. The disk files which the entries enumerate are purged (unless they have not yet been archived).

7. Compressed Results Queue

This queue contains compressed results files which have been generated by compressing the flaw data from files on the evaluation results queue. The files on the compressed results queue are ready for compressed data archive. Entries to this queue may only be removed when both primary and backup magnetic tapes have been created.

3.4.1.4 Task Execution/Priority Control

This function is actually provided via linkages with the RSX-11M operating system. This section outlines the priority system used to control task execution. Following is a description of the functions which execute at each priority level.

1. Priority Level 0

This is the highest priority level and is reserved for the operating system.

2. Priority Level 1

The Operator Interface task executes at this level. All tasks which provide inputs to or collect operator responses from this task or which queue other actions as a direct result of operator inputs also execute at this priority level.

3. Priority Level 2

All communications with remote CAUIS stations (except for data file transfers) are performed at this level.

4. Priority Level 3

All data file transfers occur at this level. Arbitration among various transfers is made based upon the queue holding the desired transfer.

5. Priority Level 4

Routines which process print and plot files into a form suitable for direct output to the Versatec printer/plotters execute at Level 4.

6. Priority Level 5

Level 5 tasks are the Statistical and Quality Assurance data extraction and compression tasks.

7. Priority Level 6

The routines which generate Quality Assurance reports execute at this level. The tasks which display the results of these operations execute at Level 1.

8. Priority Level 7

The tasks which actually perform statistical analysis execute at the lowest priority. Display of the results is performed at level 1.

3.4.1.5 System Shutdown

This task is normally used to prepare the system for power down. When executed, this function will await completion of all current tasks for the files currently being processed (evaluation, plot, data link transfer, tape data transfer, etc.) before activating the system shutdown procedure. This ensures that there will be no data loss or interruption of a task before it has properly completed its function. All queues and system parameters are saved on disk to be restored when the system is subsequently initialized. When the NET system is shut down, the user is logged off of NET and RSX-11M automatically.

3.4.2 Librarian Tasks

The Librarian is the data management system of the Nondestructive Evaluation Terminal. The Librarian's function is to identify the location of data throughout the system. The source of data for an inspected part is the inspection result file from the CAUIS station which performed the inspection. The inspection results may have been evaluated at the CAUIS before transmission or the inspector at the NET may perform the evaluation using the nondestructive inspection program (INSPECT). In either case, after evaluation, automatically the inspection results file is read to produce another data file, the statistical analysis data file. Each of these files is eventually written to magnetic tape for

permanent archival storage. It is the job of the librarian to keep up with the location of these files whether on disk or tape.

The location of files is kept in a data structure called the catalog. The catalog is structured so that file location, as well as status information about the file, can be found in several ways. For example, the catalog can be asked to list location and status of a file given the part/serial number or, given a tape reel number the catalog can list the parts on that tape.

The librarian has six functions.

- o Read CAUIS or Hold Tape function
- o Archive function
- o Recall function
- o Initialize function
- o Create backup tape function
- o Create hold tape function

These functions are described below:

3.4.2.1 Read A CAUIS or Hold Tape

This option allows the operator to read a CAUIS data tape created on one of three independent CAUIS stations, or a system overload hold tape. After this function is selected, the operator selects the read a CAUIS, or read a Hold Tape function. The operator is requested to enter the tape label on the tape to be read. After the tape label has been entered, the task will queue the job for the tape drive. When a drive is available, the operator will be prompted on the LA36 printer. If the magnetic tape label of the tape which is then mounted on the specified tape drive does not meet tape conventions, or does not match the operator specified label, a message "- Invalid Tape Label - Please Reenter" is printed on the LA36 printer. The operator should then reenter the tape label or mount the connect tape. When the connect tape has been mounted and the read CAUIS or hold tape is run, the task will read the tape. Each part file on the tape will be read in and placed in the system catalog, and a message will be printed on the LA36 printer listing the files read into the system. If any files read in the system are already in the catalog, the task will print an error

message and go to the next file. When the task has been completed, the system will inform the operator on the LA36 printer and ask for the tape to be removed from the transport.

3.4.2.2 Archive Task

The archive task performs the archive function for completed inspection data files and statistical data files. This task requires at least two drives. The archive and backup tapes are created together if an existing archive tape is to be appended. The primary tape is mounted on Drive 0 and a scratch tape on Drive 1. The system will write from the tape Drive 0 to tape Drive 1, then the system will append to both drives from disk after all files have been placed on tape. The tapes are verified to each other and to disk before the archive task completes.

3.4.2.3 Recall Task

The Recall Menu option informs the operator where a particular file(s) is located in the total NET system. The file(s) can be located on the current disk or in archive tape storage. In either case, if the computer is given:

- Part Number, Serial Number
- Serial Number
- Part Number, Date
- Tape Number

the system will locate the file(s) and display its location on the CRT.

When the operator enters the appropriate data such as part number, serial number, etc., and depresses the RETURN key, the display is as shown in Figure 49.

```
                        LIBRARIAN

                        RECALL MENU



OPTIONS:             1 - LIST THE FILES ON THE PRINTER
                     2 - LIST THE FILES ON THE SCREEN
                     3 - RECALL THE FILES
```

Figure 49 Recall Menu Display

At this time the operator may depress the GOBACK key to examine the data just typed to ensure correctness or select one of the options.

(1) The list files on the printer option, lists all of the information - part number(s), serial numbers(s), date(s), tape reel(s) on the LA 36 DECWRITER in the format shown in Figure 50.

FILE TYPE: INSPECTION RESULT

DATE: 03/01/81

TAPE REEL	PART NUMBER	SERIAL NUMBER	DATE
N81088	16T7416-5	S123456	03/01/81
N81088	16T7416-5	S234567	03/02/81
ON DISK	16T7416-5	S345678	03/03/81
N81088	16T7416-5	S456789	03/04/81
N81088	16T7416-5	S567890	03/05/81
N81088	16T7416-5	S678901	03/05/81
N81088	16T7416-5	S789012	03/06/81
N81090	16T7416-5	S890123	03/07/81
N81090	16T7416-5	S901234	03/08/81
N81090	16T7416-5	S012345	03/09/81

Figure 50 Recall List

(2) The list files on the screen option displays the same information as the list files on the printer option but on the CRT screen. Since only 10 lines of data can be displayed at one time, the PAGE key will have to be depressed to display large lists. Format same as above.

(3) Recall the files option executes the file(s) transfer from magnetic tape to disk (if applicable). When this option is selected, the operator will be prompted by the LA36 DECWRITER as to which tapes and which drives to use in a fashion analogous to that described above for Read CAUIS or Hold Tape.

3.4.2.4 Initialize Tape

The Initialize Tape option allows the operator to create magnetic labels schemes which the system can read to determine the contents of a mounted tape. The Initialize Tape option writes a volume label at the beginning of the magnetic tape per the tape conventions. If the tape has data already on it, the system warns the operator; but if the operator chooses to erase the data, the system will continue. This is the only option that allows the erasure of data that is on tape.

3.4.2.5 Create Backup Tape

The Create Backup Tape option is a routine to create a second copy (backup copy) of a primary storage tape. This option is used when only one archive copy was made at the time archival was being performed. The task will duplicate exactly, including tape label identification, the specified tape to be copied.

3.4.2.6 Create a Hold Tape

The creation of a hold tape occurs when the disk storage area approaches full capacity. At this time, the computer prompts the operator by ringing the bell on the LA36 DECWRITER. Since the lack of room on the disk system will (in effect) shut down the entire NET operation, a temporary off load of files must be made to magnetic tape. Selecting the Hold Tape option causes a list of file types to be displayed. The operator selects the file type to be temporarily stored on tape. The DECWRITER LA36 will prompt the operator to load a scratch tape on tape transport. When the tape has been mounted, the system will assign a hold tape label and will off load files to the tape making room on the NET system disks. The hold tape number will be logged into the NET system catalog giving the location of the files for recall.

3.4.3 System Status

In the system status task, a formatted display of the NET system resources and parameters is produced. This task is divided into three subtasks. In these subtasks, the overall system status, task status, and device status are displayed, shown in Figure 51.

The system status option is used by the operator to monitor the NET system. The operator can readily determine the data link(s) status, memory allocation, disk space allocation, task status, and device status.

```
20-NOV-81 14:29 MEMORY USED 77KW   DISK ALLOCATION 100MB

                MEMORY AVAIL 24KW DISK AVAILABLE    23MB

DATA LINK

STATUS                 TASK STATUS

TANK        READY      ACTIVE     2

BUBBLER 1 DOWN         WAITING    1

BUBBLER 2 ACTIVE       SCHEDULE   1

DEVICE            STATUS

TAPE 0            READY

TAPE 1            ACTIVE

LARGE             DOWN

SMALL             READY
```

Figure 51 System Status Display

3.4.4 Statistical Analysis

The statistical package allows the monitoring of ultrasonic inspection data utilizing standard statistical analysis techniques. As the statistical analysis routines must manipulate the flaw data for all parts, a technique for reducing the volume of data which must be stored is required. For the statistical analysis routines, all inspection results are first reduced to bi-state data, i.e., flaw present or absent. The data is then processed such that all flaw points with contiguous spatial location (including depth) are grouped together and characterized by the flaw center major, minor axes and orientation of best ellipse, and, also flaw depth and flaw area.

Specified flaw indications are defined as absence of ultrasonic signal given a certain threshold. Flaw indications which are contiguous in their X and Y coordinates, but which do not have the same depth, are considered to be multiple flaw indications. Each flaw is represented by an ellipse which most closely approximates the flaw shape. The flaw is then defined by the location's center position, depth, area, and the major and minor axis dimensions of the ellipse.

The Statistical Analysis capabilities require two distinct tasks: (1) Data Extraction and (2) Report and display generation.

3.4.4.1 Statistical Analysis Data Extraction

The Statistical Analysis Data Extraction task reads an inspection result file and produces a statistical analysis data compression file for the part. This extraction and data compression file is created automatically as a subtask of the system manager. All data, such as flaw size, number of flaws, part number, serial number, etc. is retained on the statistical file. Statistical analysis data for the Quality Assurance Reports is placed in the catalog for use by the Quality Assurance report generator.

3.4.4.2 Statistical Analysis Report and Display Generation

The main function for statistical analysis software is the production of flaw density functions. The statistical analysis report and display generation produces the analysis density function information for representation on either the color graphics CRT or plotter. Two density function types are available which calculate (over the part sample selected) a two or three dimensional density function for flaw location or flaw depth as described below.

The flaw density function calculates the percentage of parts in the sample with a flaw at a certain X and Y coordinate. The operator is able to specify the range of depths (threshold) which are to be allowed in forming the flaw density function. When the analysis computations are completed, the operator may select the percentage threshold thus generating a composite C-scan showing a composite of all flaws which occurred on more than the specified percentage of parts at each X, Y coordinate. (Note that if a zero percent threshold is selected, the result is a composite C-scan of all flaws on all parts). This is a three-dimensional plot. The flaw density function third dimension information is available as either a color display on the graphics terminal, or as a synthetic grey shaded plot. Once the flaw density function option is selected, all prompts and responses will be from the color graphics terminal, in a manner analogous to that described later for the nondestructive inspection program (Section 3.4.6). The percentage thresholds are interactively adjusted from the color graphics terminal through the same procedures which control amplitude or depth thresholds for the inspection program. The depth density function calculates the flaw depth density function estimate. This is displayed as a variation of flaw occurrence with depth. It is a two dimensional plot.

3.4.5 Quality Assurance Reports

The Quality Assurance Report is a periodic review that gives management personnel information on the status of the CAUIS stations and the parts that have been inspected by the CAUIS network. The time interval for these reports is weekly, monthly, and special (on demand). The reports have two versions: regular and extended. In the regular version, summary information about each part number is compiled. In the extended

version, the serial numbers inspected for each part number are delineated. New data is added to the reports each week to show manufacturing trends. Additional comments by the Q. A. engineers are added after the report is created.

Material for the Quality Assurance Report is drawn from three distinct tasks, which are briefly outlined below.

- o In the quality assurance data extraction task, an inspection result file is read, and a Q. A. data compression file for the Q. A. data base is produced. This extraction and data compression file is created automatically as a subtask of the system manager.

- o In the quality assurance analysis generator task, the basic report is generated, either at specific calendar points or upon operator request. The results and plots are placed on disk files and entered into the print/plot spooler queue with a hold status.

- o The quality assurance report generator allows the operator to preview the report results on the console and append a limited set of operator input comments. This limited editing capability is not saved for republishing.

There are two types of Quality Assurance reports: a tabular and a plotted report. The tabular report consists of a summary of parts inspected by each inspection system and the disposition of the parts inspected, Figure 52. A special report displays each serial number of the parts inspected by inspection system and disposition. An example of this report is in Figure 53.

WEEKLY ACTIVITY
REPORT DATE: 28-JUN-82

START DATE: 01-JAN-82
END DATE: 07-JAN-82
PAGE 1

PART NUMBER	IMMERSION # 1			BUBBLER # 1			BUBBLER # 2			TOTAL		
	AC	RJ	HD	AC	RJ	HD	AC	RJ	HD	AC	RJ	HD
16T7226 007	15	16	15	16	15	15	15	15	15	45	45	45
16T7226 008	15	15	16	15	15	15	15	16	15	45	46	46
16T7307 003	15	15	15	15	16	15	15	15	15	45	46	45
16T7307 004	16	15	15	15	15	16	15	15	15	46	45	45
16T7416 005	15	15	15	15	15	16	15	16	15	45	45	45
16T7416 006	15	15	15	16	15	15	15	15	16	46	45	46
16T7464 3	16	15	15	15	15	15	15	15	16	46	45	45
16T7465 4	14	15	15	15	15	14	16	14	15	45	44	44
TOTAL:	121	121	121	122	121	121	121	121	122	364	363	364

Figure 52 Inspected Parts Summary Report

PARTS ACCEPTED

WEEKLY ACTIVITY EXTENDED
REPORT DATE: 28-JUN-82

START DATE: 01-JAN-82
END DATE: 07-JAN-82
PAGE 1

PART NUMBER 16T7226 807	IMMERSION # 1	BUBBLER # 1	BUBBLER # 2
	S000742	S000382	S000286
	S000766	S000406	S000310
	S000790	S000430	S000334
	S000814	S000454	S000358
	S000838	S000478	S000022
	S000862	S000502	S000046
	S000886	S000526	S000070
	S000910	S000550	S000094
	S000934	S000574	S000118
	S000958	S000598	S000142
	S000982	S000622	S000166
	S001006	S000646	S000190
	S001030	S000670	S000214
	S001054	S000694	S000238
	S001078	S000718	S000262
TOTAL:	15	15	15

Figure 53 Part Disposition Report

The plotted data will be a 4-week moving average quantitized by week covering a 1-year interval. Each new week will be added to the graph to show manufacturing trends. The graph parameters shown in Figure 54 will be plotted:

Dependent Axis		Independent Axis
o	Total number of parts	Calendar time
o	96 Accepted parts	Calendar time
o	96 Rejected parts	Calendar time
o	Total number of flaws	Calendar time
o	Area of flaws per part	Number of parts
o	Number of flaws per part	Number of parts
o	Ratio of flaw area to total flaw area	Number of parts

Figure 54 Manufacturing Trends Report

3.4.6 Nondestructive Inspection Program

The objective of the inspect program is the evaluation of the inspection data or statistical analysis results in graphic form. Included in the NET system are two DEC/VT-100 terminals. One is the primary system control terminal. The second VT-100 is dedicated to and is an integral part of the graphic display system. The inspection program allows the inspector to select a file for evaluation from a list of queue contents displayed on the VT-100 terminal. The contents of the list are dependent upon the queue selected, i.e., the Work Queue, Special Evaluation Queue, MRB Queue, or Statistical Analysis Results Queue.

After a file has been selected for evaluation, the Inspection Data Header is displayed on the V-100 with options to perform the following functions:

- o Change Evaluation Parameters
- o Reset To Default Evaluation Parameters
- o Reset To Stored Evaluation Parameters
- o Enter Disposition
- o Reset C-Scan
- o Cross Hair Center
- o Cross Hair Area
- o Large Plot
- o Cancel Last Command
- o Bring Up Next Part For Evaluation
- o Go Back

3.4.6.1 Evaluation of Inspection Data

These functions enable the inspector to evaluate the inspection data gathered from the ultrasonic inspection machines or resulting from a requested statistical analysis. Four major sections make up the INSPECT program and are identified on the Graphic Terminal Menu display. The Inspect menus are displayed on the VT-100 terminal screen as shown in Figure 55.

```
GRAPHIC TERMINAL MAIN MENU

OPTIONS:  1.  DISPLAY WORK QUEUE

          2.  DISPLAY MRB QUEUE

          3.  DISPLAY SPECIAL EVALUATION QUEUE

          4.  DISPLAY STATISTICAL ANALYSIS RESULTS
              QUEUE
```

Figure 55 Graphic Terminal Main Menu

The Work Queue, MRB Queue, Special Evaluation Queue, and Statistical Analysis Results Queue are defined and their functions are explained in the System Manager Section of this report. The operator is able to select a queue typing the number displayed beside the desired option. The option indicated will be displayed in reverse video. The operator can change options by typing in another number. the reverse video will move to the new selection. The operator is also able to select an option using the "up" arrow key. When the arrow key is pressed the reverse video will move the menu up or down in the direction indicated by the arrows. After the queue selection is made, the ENTER key is depressed to initiate the functions.

3.4.6.2 List of Queue Contents

When one of the four queue options is selected, a list of queue contents is displayed on the VT-100 CRT screen. After the queue contents are displayed, the inspector is then able to select a file for evaluation. The file is selected by typing the number displayed beside the file name or by using the "up" or "down" arrow key to move the cursor to the file name. The selected file name will be displayed in reverse video. When the desired file name has been selected, depressing the ENTER key causes display of the evaluation menu.

3.4.6.3 Inspection Data Header

When the file is selected, the Inspection Data Header block for that file is displayed on the CRT as a part of the evaluation menu, Figure 56. The purpose of this area is to identify each inspection file and give a quick reference to information without generating a C-Scan.

INSPECTION DATA HEADER

PART NUMBER	: 16W112-11	PART NAME	: RIR WING PYLON BL71
INSP TIME	: 4-SEP-31 21:32	PROGRAMMER	: RON STANFILL
PROGRAM STAT	: RELEASED REV02	STAT DATE	: 31-JAN-80 21:15
SERIAL NO	: F103713A-19	IR PANEL	: K196081
TRANSDUCER	: 12345678	MACHINE #	: BUBBLER #2
INSPECTOR	: MAY	DISPOSITION	: 0

Figure 56 Inspection Data Header

INSPECTION DATA HEADER

PART NUMBER	: 16W112-11	PART NAME	: RIR WING PYLON BL71
INSP TIME	: 4-SEP-31 21:32	PROGRAMMER	: RON STANFILL
PROGRAM STAT	: RELEASED REV02	STAT DATE	: 31-JAN-80 21:15
SERIAL NO	: F103713A-19	IR PANEL	: K196081
TRANSDUCER	: MAY	DISPOSITION	: 0

EVALUATION FUNCTIONS

1 CHANGE EVALUATION FUNCTIONS

2 RESET TO DEFAULT EVALUATION PARAMETERS

3 RESET TO STORE EVALUATION PARAMETERS

4 ENTER DISPOSITION AC HL RJ

5 RESET C-SCAN

6 CROSS HAIR CENTER

7 CROSS HAIR AREA

8 LARGE PLOT

DATA EVALUATION PARAMETERS

THRESHOLD:	RANGE:	4	SCALE FACTOR:		
1. Amp	1	5	1:2	2:1	1:1
2. Depth	2	6	1:4	4:1	
	3	7	1:8	8:1	

ERROR MESSAGE

Figure 57 Evaluation Functions and Evaluation Parameters

Following the Inspection Data Header on the CRT screen is a list of Evaluation Functions and Data Evaluation Parameters shown in Figure 57. The following section describes the Evaluation Functions and Evaluation Parameters used for part (or statistical analysis) evaluation.

3.4.6.4 Evaluation Functions

After a file has been selected for evaluation, the inspector is able to select the desired evaluation functions by typing the number displayed beside the evaluation functions or by using the "up" and "down," and "left" and "right" arrow keys to move the cursor to the desired function. The selection will be displayed in reverse video. Pressing the ENTER key enters the selection. Until the selected evaluation function is completed, the function will blink to indicate the active function.

The following paragraphs identify the evaluation functions, evaluation parameter and operator interactions.

3.4.6.4.1 Change Evaluation Parameters

The Change Evaluation Parameters option allows the operator to change evaluation parameters associated with a display for flaw evaluation. When display of a file with a blank disposition field has been requested, a predetermined set of default values (based on part number) are displayed. A file with a disposition code will initially display the parameters in effect when the file was last evaluated. The evaluation parameters are located on the CRT screen in the Data Evaluation Parameter area. When the Change Evaluation Parameter function is selected the cursor will move to the Data Evaluation parameter area on the CRT screen. The existing parameters can be changed by tabbing to the appropriate display and typing in the unprotected field following the parameter. The arrow keys may also be used to move the cursor to the unprotected fields. This function allows the operator to reenter parameters if an error has been made in the input (typing, etc.). The unprotected field following the parameters will flash until the parameter data has been entered. The parameters will then be displayed in reverse video. If the operator does not wish to change the existing parameter, he can move to the next parameter by pressing

the TAB key. When all changes have been made to the evaluation parameters, the operator presses the ENTER key. The changes will be immediately reflected on the color graphic display (Figure 58 is a sample display). The operator can then select which function is needed to further evaluate the part. Cancel Last Command may be used before ENTER key is pressed to return the operator to the Evaluation Function options. If Cancel Last Command is used, any changes made to the evaluation parameters will not be recognized, and the original value of the parameters will be returned to the display.

The Thresholds assign a color (or gray scale, if plotting) designation to each decibel range which is indicated on a color bar. The color bar is a 1/2" x 7" vertical bar with colors spaced along the length (1-7). Each specific color corresponds to a decibal range denoting the extent of the range. The color bar and the corresponding decibel range are displayed on the color graphic terminal along with the area to be inspected, Figure 58. The ranges have color definition as follows:

Range 1	=	RED
Range 2	=	YELLOW
Range 3	=	GREEN
Range 4	=	LT BLUE
Range 5	=	DARK BLUE
Range 6	=	PURPLE
Range 7	=	WHITE
CRT Background	=	BLACK

The first parameter the operator is allowed to change is threshold type. A choice is given the operator to display amplitude or depth data. The operator selects depth or amplitude by entering option one on the inspection CAT terminal and selecting depth or amplitude with the arrow keys. The graphics system will then display the proper data with the correct color bar. After a graphics display has been produced the operator can change the color bar thresholds by pressing the up or down arrow keys to change the color threshold of a color range. To change color ranges the operator presses the ENTER key and the graphics system moves the threshold cursor to the next range.

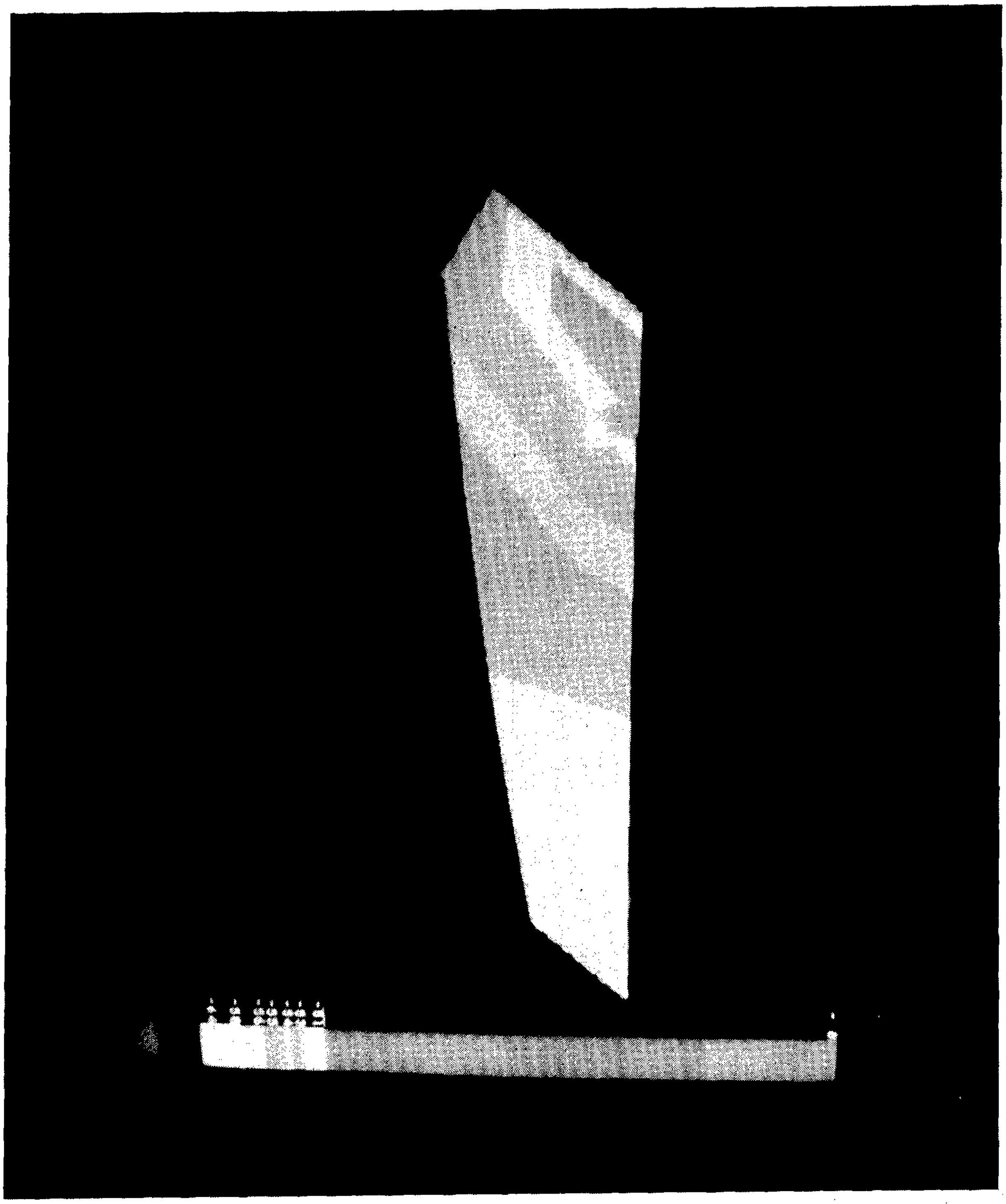


Figure 58 Graphics Display Showing Inspection Part and Color Bar

3.4.6.4.2 Reset To Default Evaluation Parameters

There are two areas on the disk where stored evaluation parameters exist. Each area will have two threshold tables: one for amplitude and one for depth. Reset To Default Evaluation Parameters selects one of these stored parameter sets and displays on the CRT and the color graphics terminal the original Default Evaluation parameters as if the data were just received from a CAUIS with no evaluation.

3.4.6.4.3 Reset To Stored Evaluation Parameters

The second stored parameter set (Last Evaluation Data Parameters) contains the parameter data used in the last evaluation. Depending on whether amplitude or depth is selected, Reset To Stored Evaluation Parameters will display on the CRT the last evaluation data parameters as if the data were just recalled after prior examination evaluation.

3.4.6.4.4 Enter Disposition

The Enter Disposition function allows the inspector to update the disposition area of the Inspection Data Header and write the data evaluation parameters on the reserved area of the inspection file after the Inspection Data Header.

The disposition is displayed in unprotected fields following the Enter Disposition function. The operator will tab to the appropriate disposition; the disposition will be displayed in reverse video. The operator will press the ENTER key to enter the disposition. After a disposition has been made, the file will be updated and moved to the appropriate queue. The four valid dispositions are:

No Evaluation

AC - Accept
HD - Hold
RJ - Reject

The following paragraphs describe the dispositions and where the files will be placed:

Blank Disposition --- If the disposition is blank (spaces), the computer will place the part back on the evaluation queue with no change.

Accept Disposition --- Accept Disposition is entered when the part is formally accepted by Quality Control. Accept Disposition will place file name in Archive Queue and remove the file name from Work Queue.

Hold Disposition --- Hold Disposition is entered when a part is of substandard quality and awaiting Material Review Board action. The file name will be placed in the MRB Queue and removed from the Work Queue.

Reject Disposition --- Reject Disposition is entered when the part is formally rejected by Material Review Board personnel. Reject disposition is a valid disposition only when used by the Material Review Board and when the file comes from the MRB Queue. If the file is from the MRB Queue, Reject Disposition will be accepted and the file will be removed from the MRB Queue and placed in the Archive Queue. If the file is not from the MRB Queue, an error message will be printed in the Error Message area which will tell the inspector Reject Disposition is invalid. The inspector will be instructed to enter Hold Disposition.

3.4.6.4.5 Reset C-Scan

Reset C-Scan option is used to display the initial C-scan on the color graphic terminal. Examples of a C-scan are shown in Figures 59 and 60. A default scale factor will be used to allow the complete outline of the part to be displayed at the maximum size possible on the color graphic screen. Reset C-Scan option is also used to reset the graphic display back to the initial C-scan after a flaw has been evaluated using the cross hair center, or cross hair area displays. Reset C-Scan option does not affect the threshold parameters displayed in the Data Evaluation Parameter area on the CRT screen.

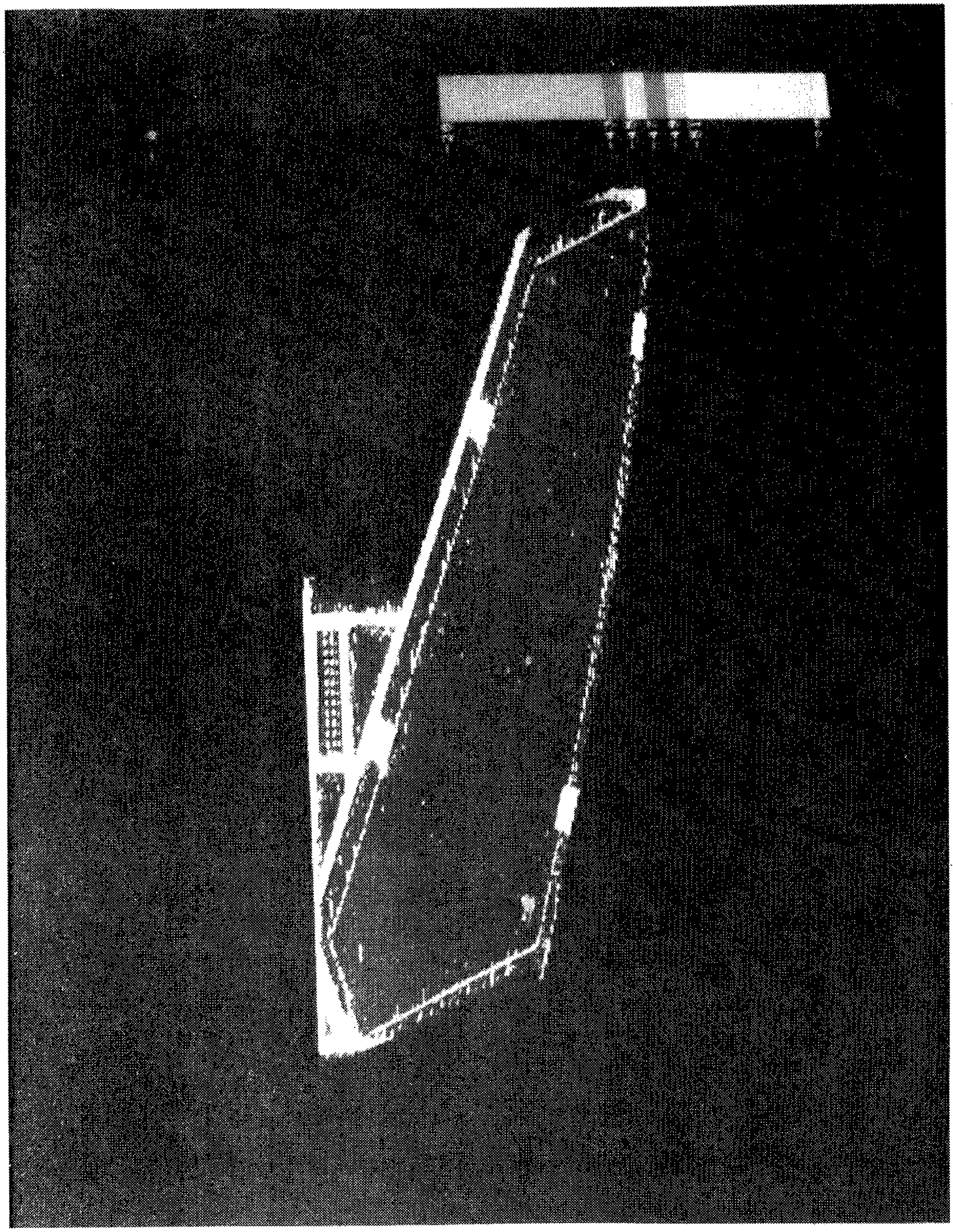


Figure 59 Typical Graphic Display of C-Scan

Figure 60 Enlarged Display of C-Scan

3.4.6.4.6 Cross Hair Center

Cross Hair Center function will generate a movable cross hair on the CRT display at the center of the screen. The operator will be able to move the cross hair in the inspection data area of the display using the VT100 arrow keys. When the operator reaches the area desired, depressing the ENTER key will center on the CRT display the area around the cross hair at full-scale (1:1), Figure 61. Cancel last Command will cancel the cross hair command, clear the cross hair from the screen, and return the operator to the Evaluation Functions options.

3.4.6.4.7 Cross Hair Area For Targeting

Cross Hair For Area Targeting function will generate a movable cross hair on the color graphic display at the center of the screen. The operator will be able to move the cross hair in the inspection data area of the display using the VT100 arrow keys. The operator will decide on two points that are on the diagonal of a rectangle. When the cross hair is placed at each point, the operator depresses the ENTER key. After both points have been defined, the computer will draw a rectangle through the two points and display the area on the CRT at the scale factor required to fill the CRT screen, Figure 62. Any time prior to entering both points, the operator may depress the Cancel last Command key to cancel the cross hair, clear the cross hair from the screen, and return the operator to the Evaluation functions options.

3.4.6.4.8 Large Plot

Large Plot is the plot package for the Versatec 8172A 72" wide plotter. The function of the Large Plot is to plot whatever is on the color graphic display using the dimensional scale factor indicated in the Data Evaluation Parameter area.

The scale factor is the dimensional magnification of reduction factor that determines the size of the inspection plot on the large plotter. After the inspector selects the large plot function he must select the proper scale factor through the use of the up and

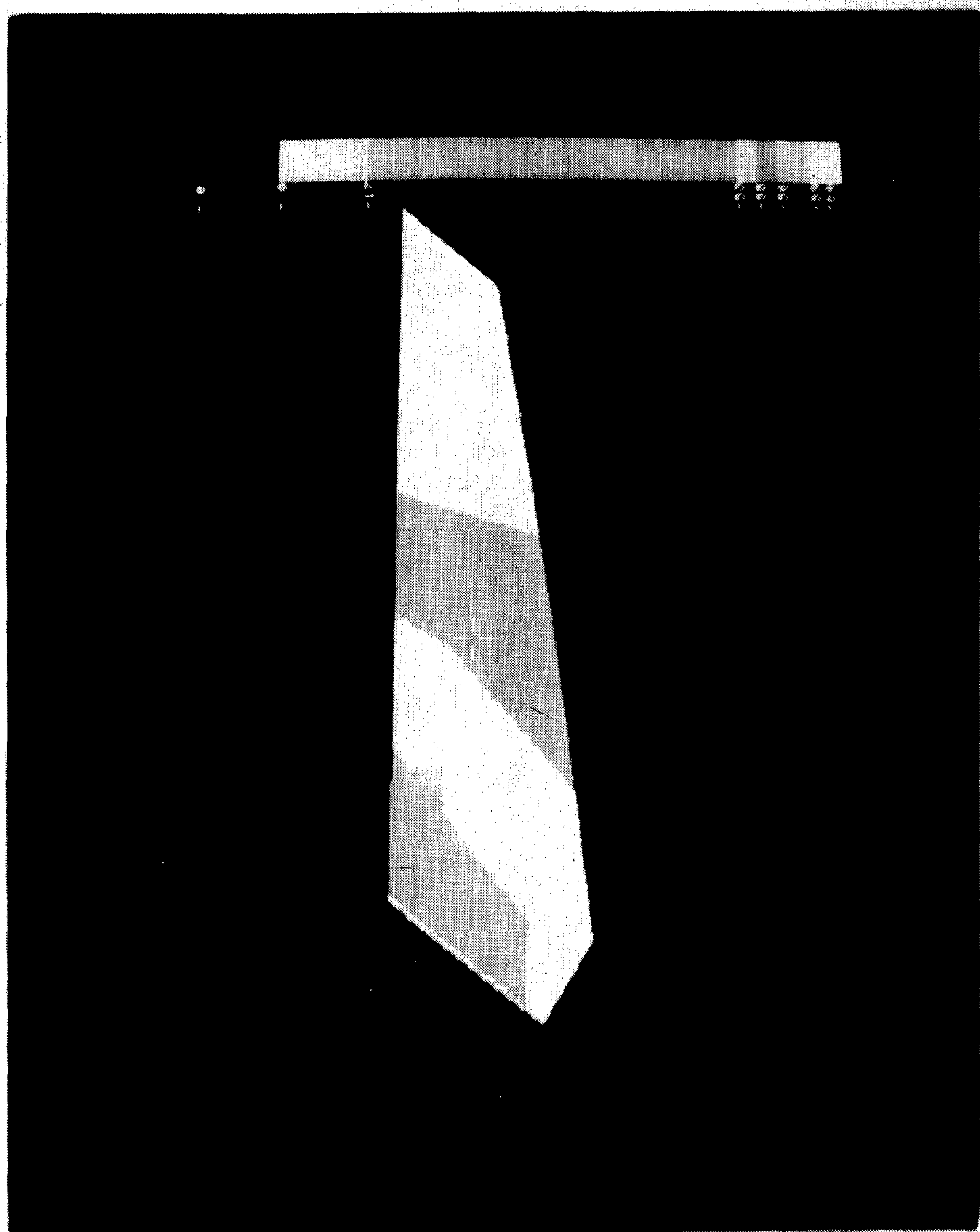


Figure 61 Graphic Display Showing Cross-Hair

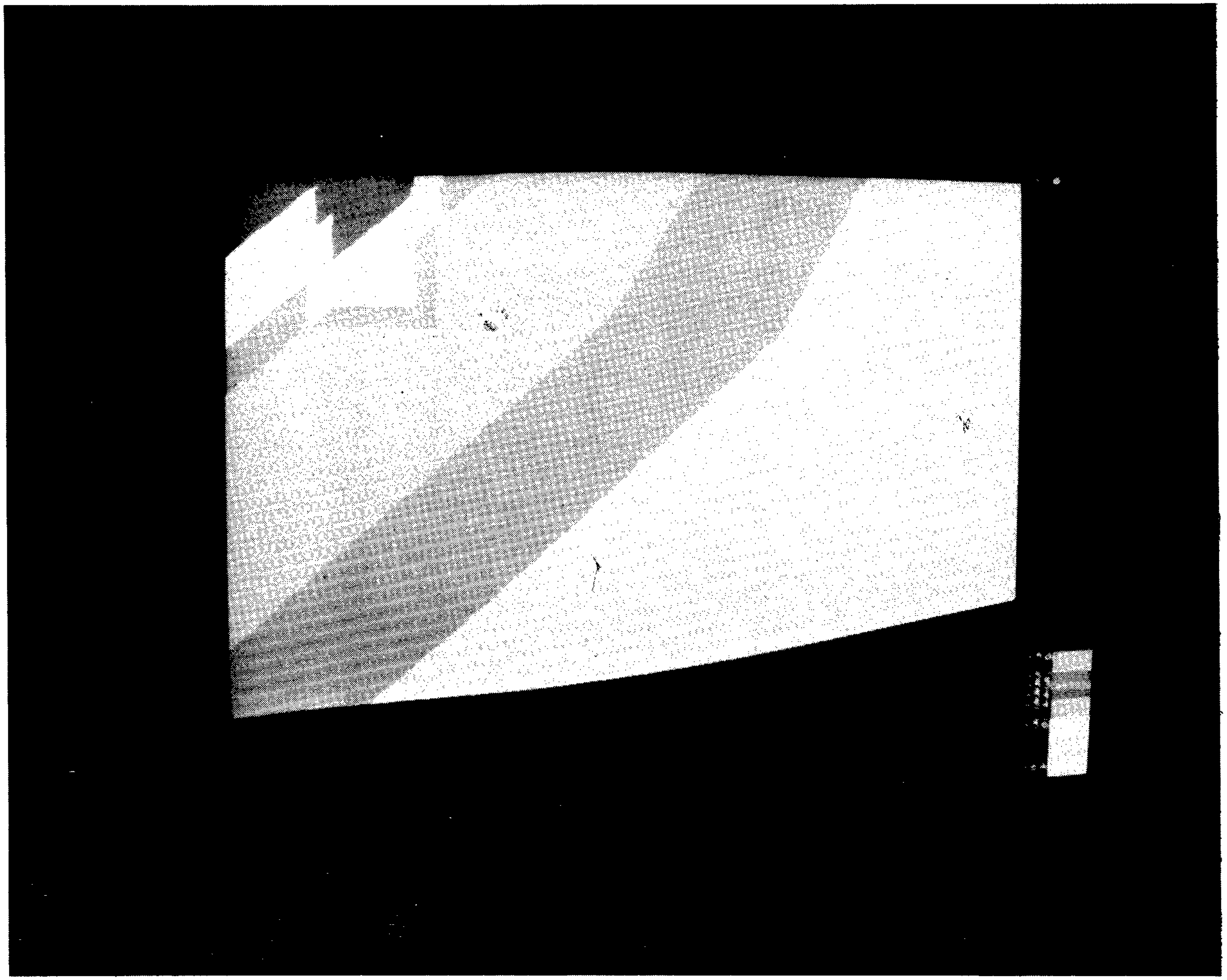


Figure 62 Inspection Area Is Enlarged to Fill Screen

down arrow keys. Pressing enter will enter the specified scale factor and start the plot process. The allowable scale factor values are listed below the scale factor area.

EXAMPLE:	Scale	Factor	
	1:2	2:1	1:1
	1:4	4:1	
	1:8	8:1	

The computer will place the X (long) axis in the direction of paper motion and place Y axis in the 72 inch direction.

3.4.6.4.9 Cancel Last Command

Cancel Last Command function allows the operator to cancel an evaluation function without going back to the main Menu.

3.4.6.4.10 Bring Up Next Part For Evaluation

After disposition is made on a part, the operator can bring up the next file for evaluation by pressing the go back key. The program will go back to the list of Queue contents. If the inspector wishes to return to the main Menu in order to change Queues, he can do so by depressing the GO BACK key. The GO BACK function key allows the operator to go back to the main Inspect Menu which allows selections of one of the four queues.

4.0 COST SAVINGS/PERFORMANCE

The incorporation of the multiple element array transducer provides a wide "paint brush" sweep of F-16 empennage composites. In addition, the CAUIS has the capability of following the outline of varying shaped composites. These combined features drastically reduce inspection time as compared to the existing ultrasonic immersion system.

Being computerized, the CAUIS is capable of producing C-scan printouts of ultrasonic inspection data. This is especially beneficial to the CAUIS operator over the old immersion system. In that, the CAUIS operator can request from the master menu, on the VT-100 terminal, a full size C-scan of ultrasonic inspection results instead of pasting together several C-scan sheets to equal the actual size of the part inspected. Also, the amount of discrete operations performed by the operator is minimized to run the CAUIS.

Overall the CAUIS provides a substantial cost savings for the high volume inspection of aircraft composite structures and quality data gathering-retention of ultrasonic inspection results.

5.0 CONCLUSIONS

The results of work performed during this program have culminated in the development of an automatic ultrasonic scanning inspection system. Inspection results obtained by CAUIS are easily accessable. C-scan data can be output in gray scale or conventional (black and white) format. Figures 63 and 64 illustrate the types of C-scan output data of the old immersion system and the CAUIS. The "white" areas of these two C-scan printouts indicate that flaws (signal amplitude below a per-set threshold level) exist within the part. The "black" areas indicate that part integrity is within the threshold level setting. From the CAUIS C-scan results it appears sensitivity is greater.

The evaluation of CAUIS and NET system performance at the conclusion of development activities has been assessed. The overall assessment of CAUIS and NET system performance has been organized into two topics of discussion; system capabilities and limitations, for each system.

The following list details performance capabilities of the CAUIS operating at production rates.

- Inspection of flat parts only
- Availability of 8 levels of gray shading with C-scan results

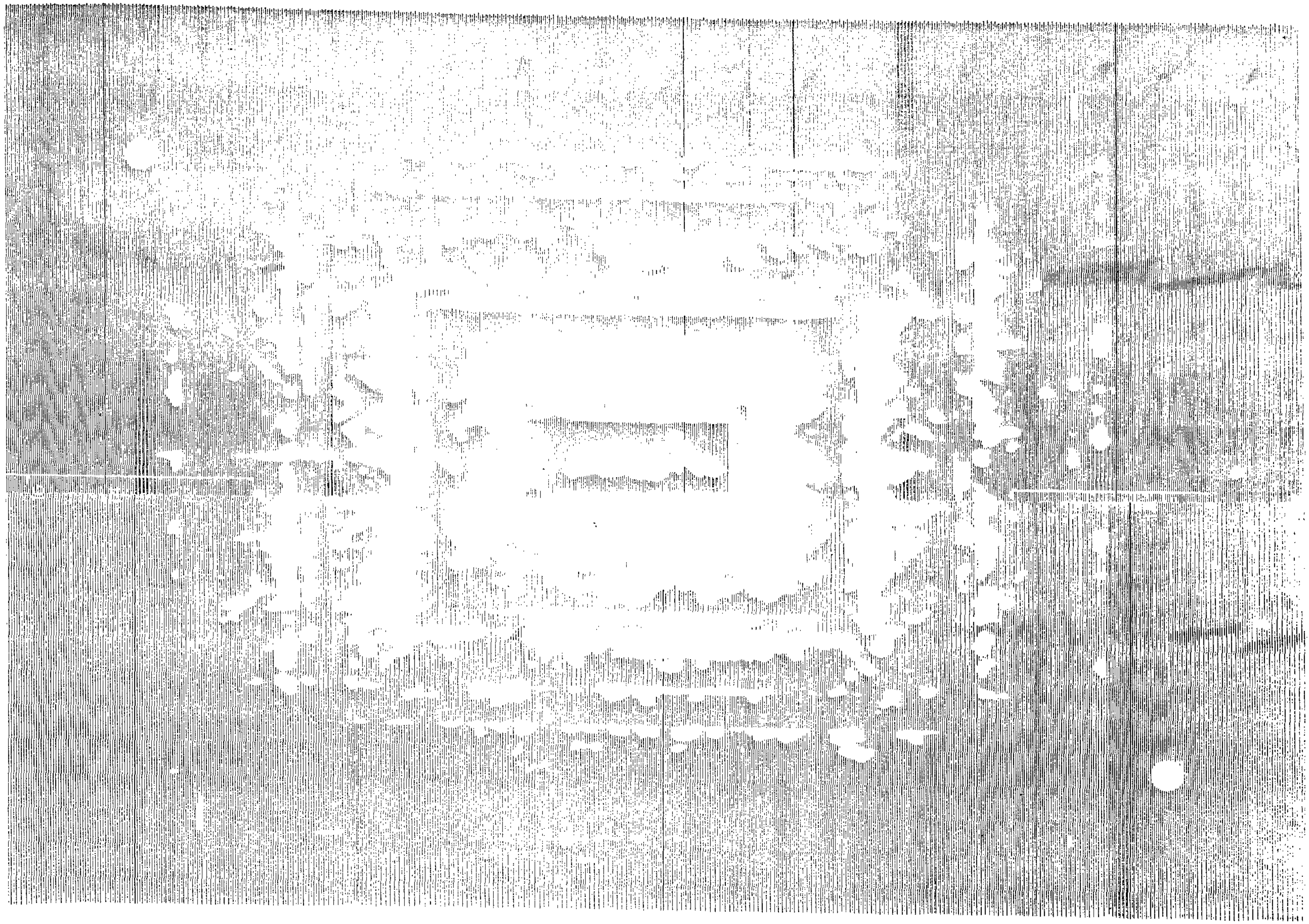


Figure 63 Conventional Immersion C-Scan

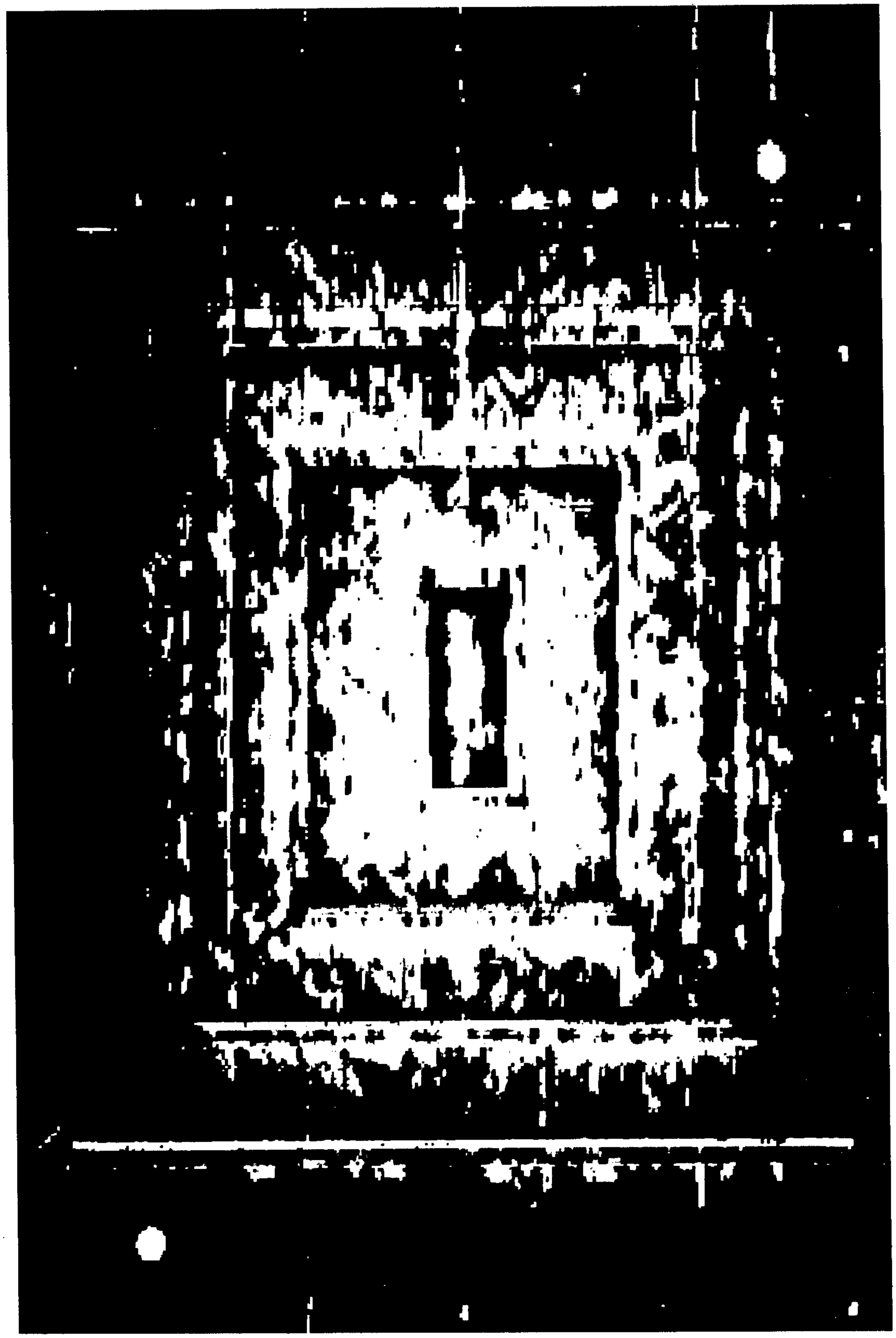


Figure 64 CAUIS C-Scan

- o Data compression of inspection results
- o Inspection rate: 10.24 sq. inch area scanned per second versus
  conventional immersion inspection rate of 1.6 square inch area scanned per second.
- o Adequate array transducer sensitivity for thin composites less than 1/2" thick with a 2.75 inch sound focal length.
- o Distance amplitude compensation for variable part thicknesses; 37db receiver amplifier gain.
- o Easy operator control from VT-100.
- o Constant encoder position feedback to 80/30 microcomputer.
- o Optional single channel inspection.
- o Flaw resolution within $\pm$ .080".
- o Scan pattern follows outline of part shape.
- o Output of "raw" ultrasonic inspection data retrieveable for resolving flaw data accuracy.
- o Reductioin of total inspection time by 90%.
- o Computer storage of inspection results.

The CAUIS has limits to its capabilities based on the current hardware/software design. These limitations can be overcome by alternative CAUIS upgrade designs or modifications to existing hardware. The limits of CAUIS hardware capabilities are labeled and discussed below for better understanding:

1. Complex shape part inspection - The inspection of F-16 contoured complex composites is not possible with the CAUIS. The search unit (multiple element array transducer holding fixture) is not mobile, which creates problems when orthagonality of sound beam to part must be maintained. Sonic reception by the array transducer is drastically degraded due to Snells law and refraction.

2. <u>Gray scale shading of C-scan inspection results</u> - The eight various black to white shades selected were of help resolving the differences of signal amplitude attenuation, scaled in decibels. However, no significant improvements in resolving ultrasonic flaw indications were realized with gray scale/C-scan inspection results.

3. <u>Inspection of composites greater than .5" thick.</u> - The CAUIS can accurately inspect composites up to a maximum of .5 inch thick. This data is based on the array transducer operated at low power (30 vp-p DC) and a focal length of 2.75 inches.

The following list details performance capabilities of the NET system in a production environment.

- o Acquisition of CAUIS data in a totally unattended mode
- o Automatic recovery after power fail
- o High speed color graphics display of CAUIS amplitude and depth information
- o Variable scale plots of inspection results
- o Grey scale plots keyed to color graphics color bar
- o Archival of compression results for historical statistical analysis of inspection results
- o Statistical analysis of inspection results
- o Plots of statistical analysis data
- o Color graphics statistical presentation of flaw areas
- o Automatic weekly and monthly quality assurance reporting
- o Archival of inspection results on magnetic tapes

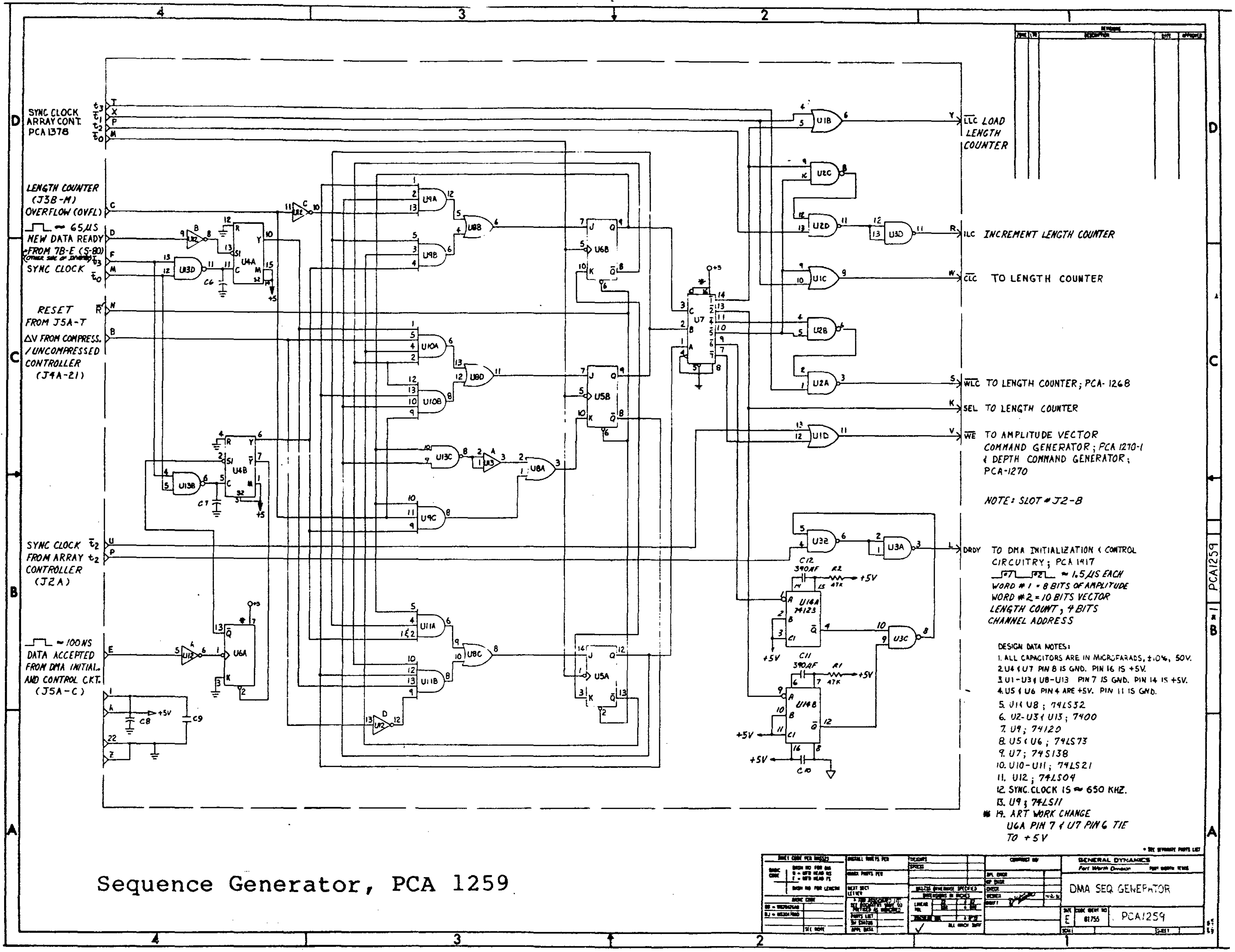
When the CAUIS stations are upgraded to allow inspection of complex contoured parts, a related expansion in NET capability will be required to allow the advanced display and evaluation capabilities for these contoured parts that currently exists for the near planar parts.

Finally, the NET system has met or exceeded all requirements as specified by the Nondestructive Evaluation Terminal functional design. The NET system is today more advanced than the inspection tools providing the NET with data. The advanced development of the NET system will increase the productive life of the system making it a more valuable data management system. The NET system is now integrated with the CAUIS system and is in the process of being linked to the Automation Industries Production Bubbler System.

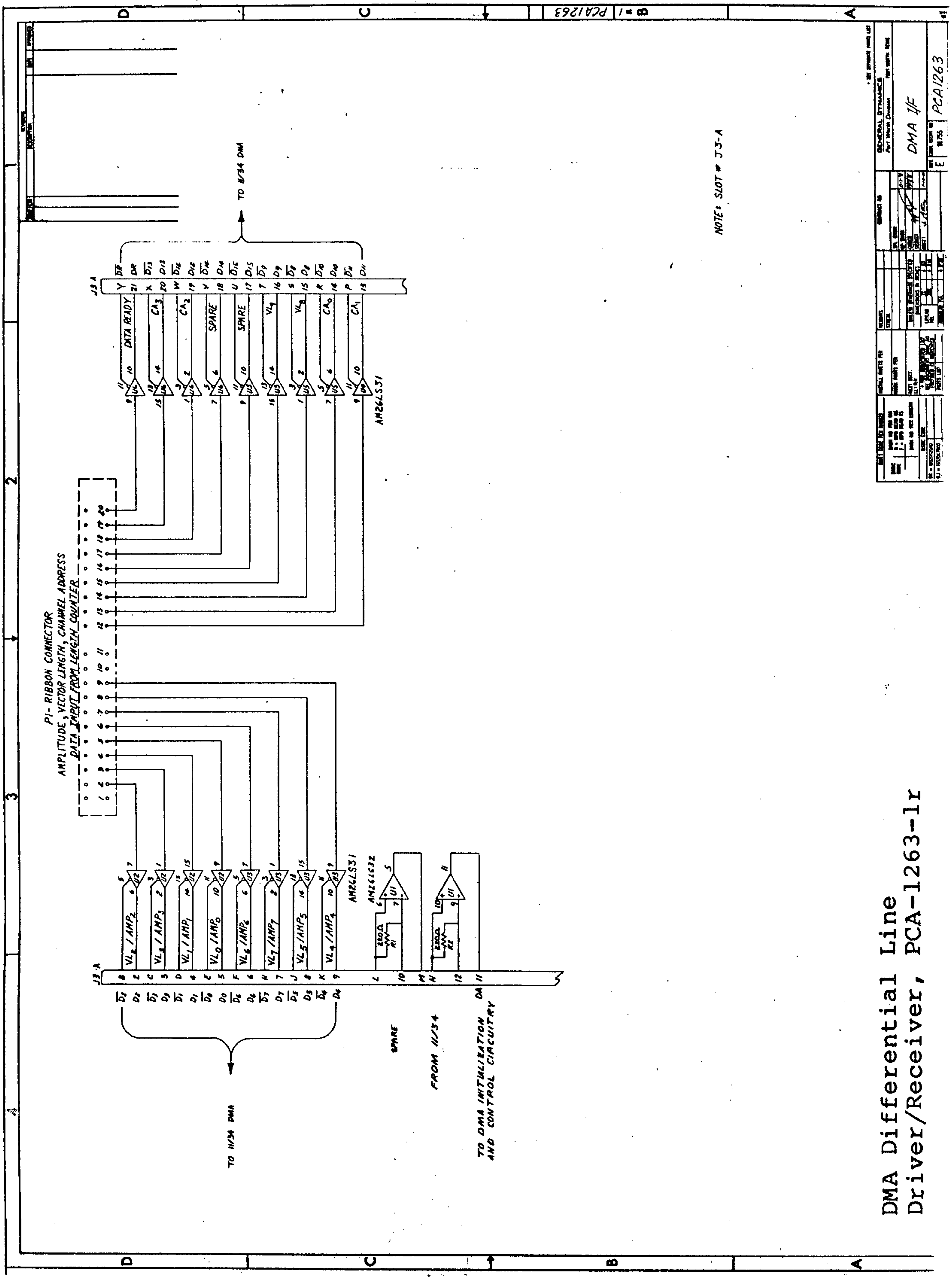
The NET system stands ready to serve the Quality Assurance Department for years to come providing a strong evaluation tool and improved management information to aid the production of composite aircraft structures for General Dynamics.

A P P E N D I X

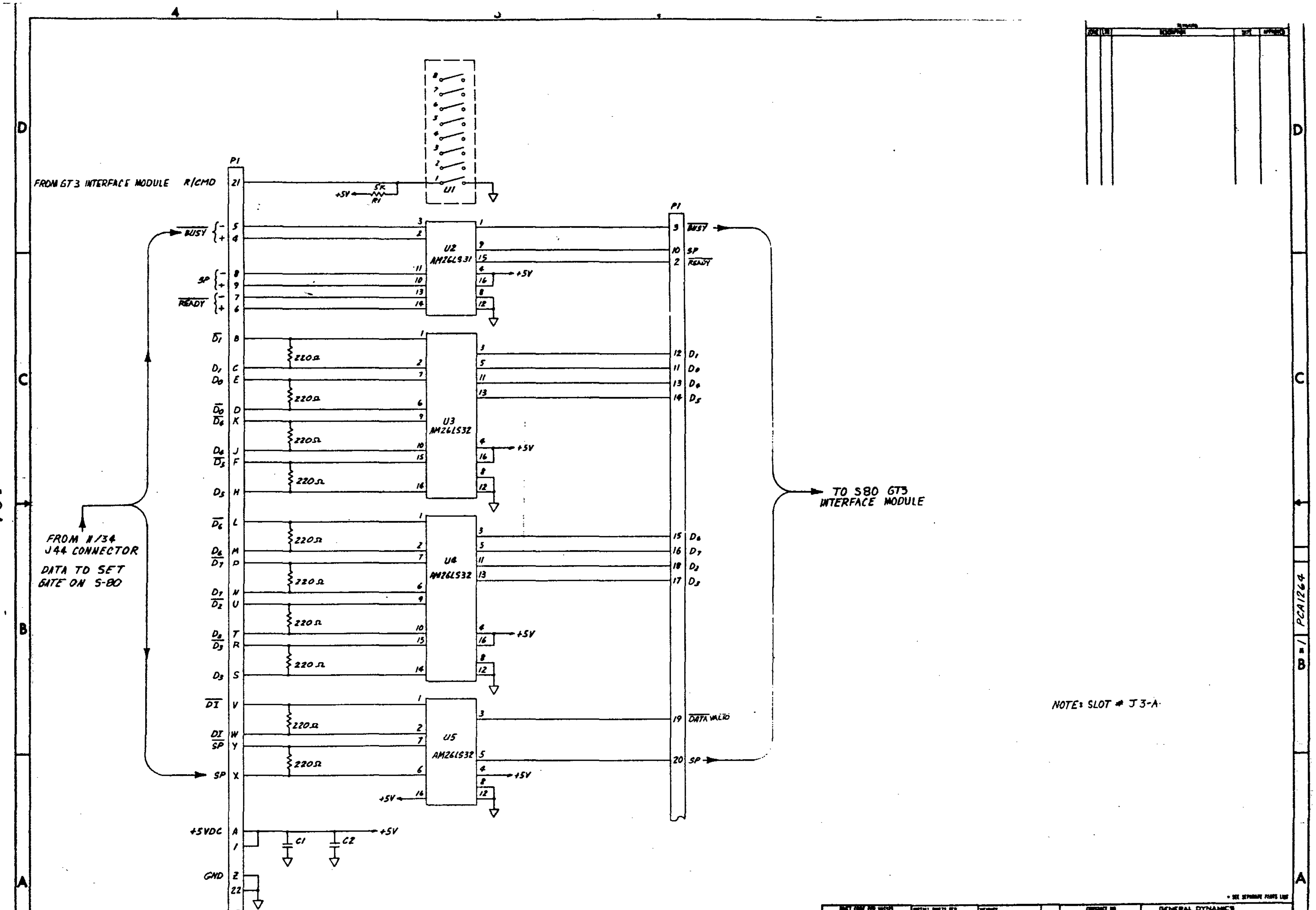
GENERAL DYNAMICS' DESIGNED ULTRASONIC HARDWARE SCHEMATIC DIAGRAMS



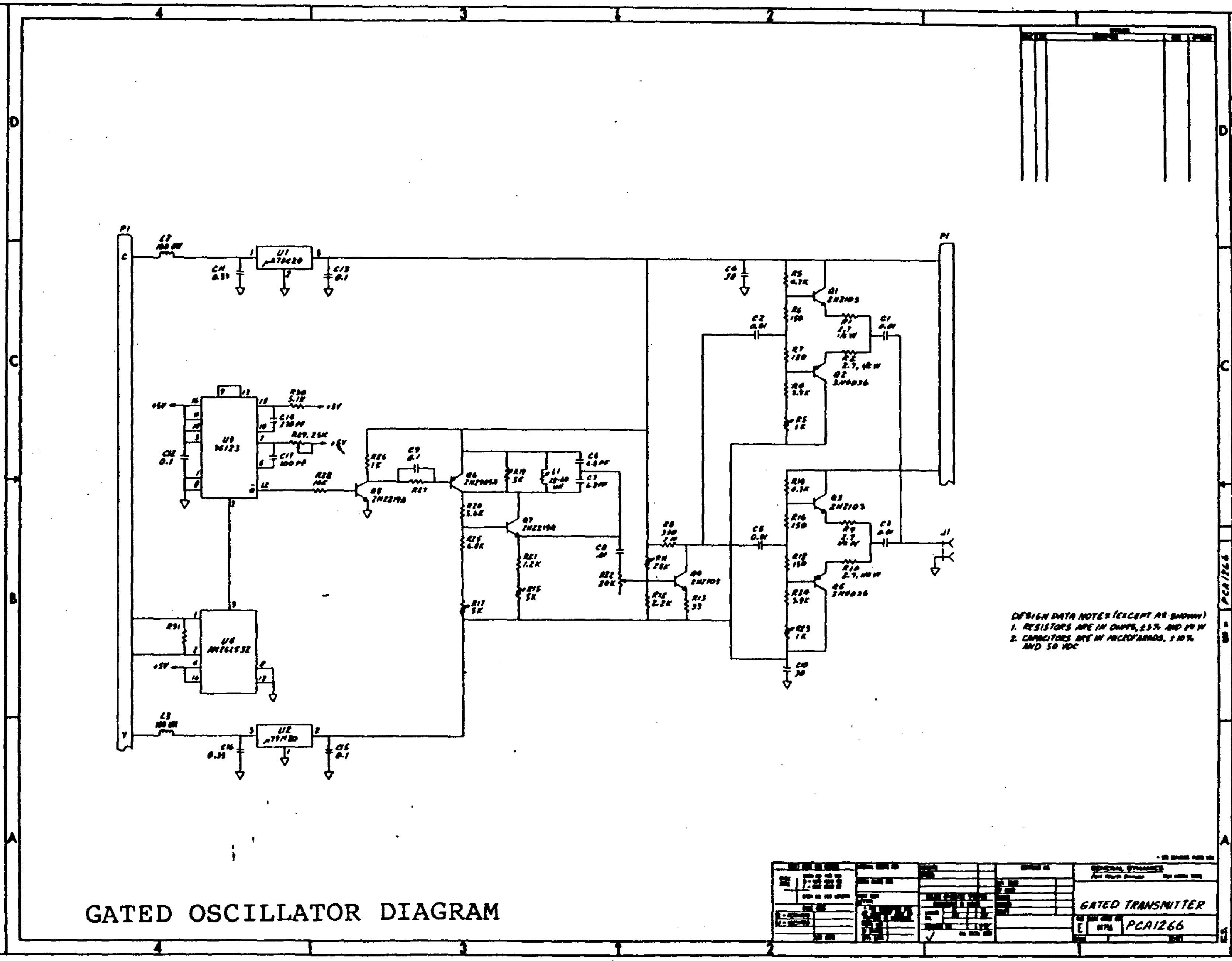
Sequence Generator, PCA 1259



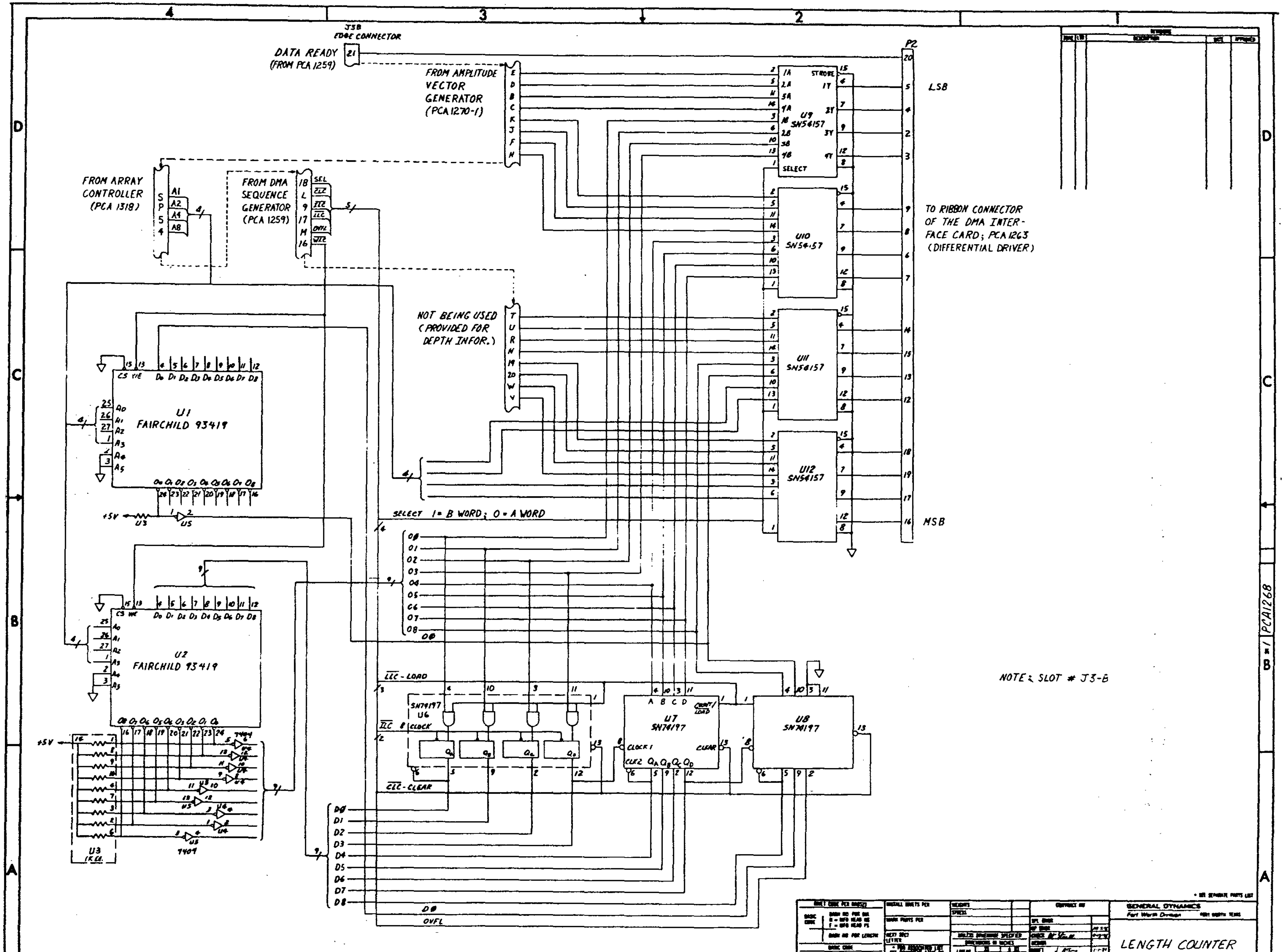
DMA Differential Line Driver/Receiver, PCA-1263-1r



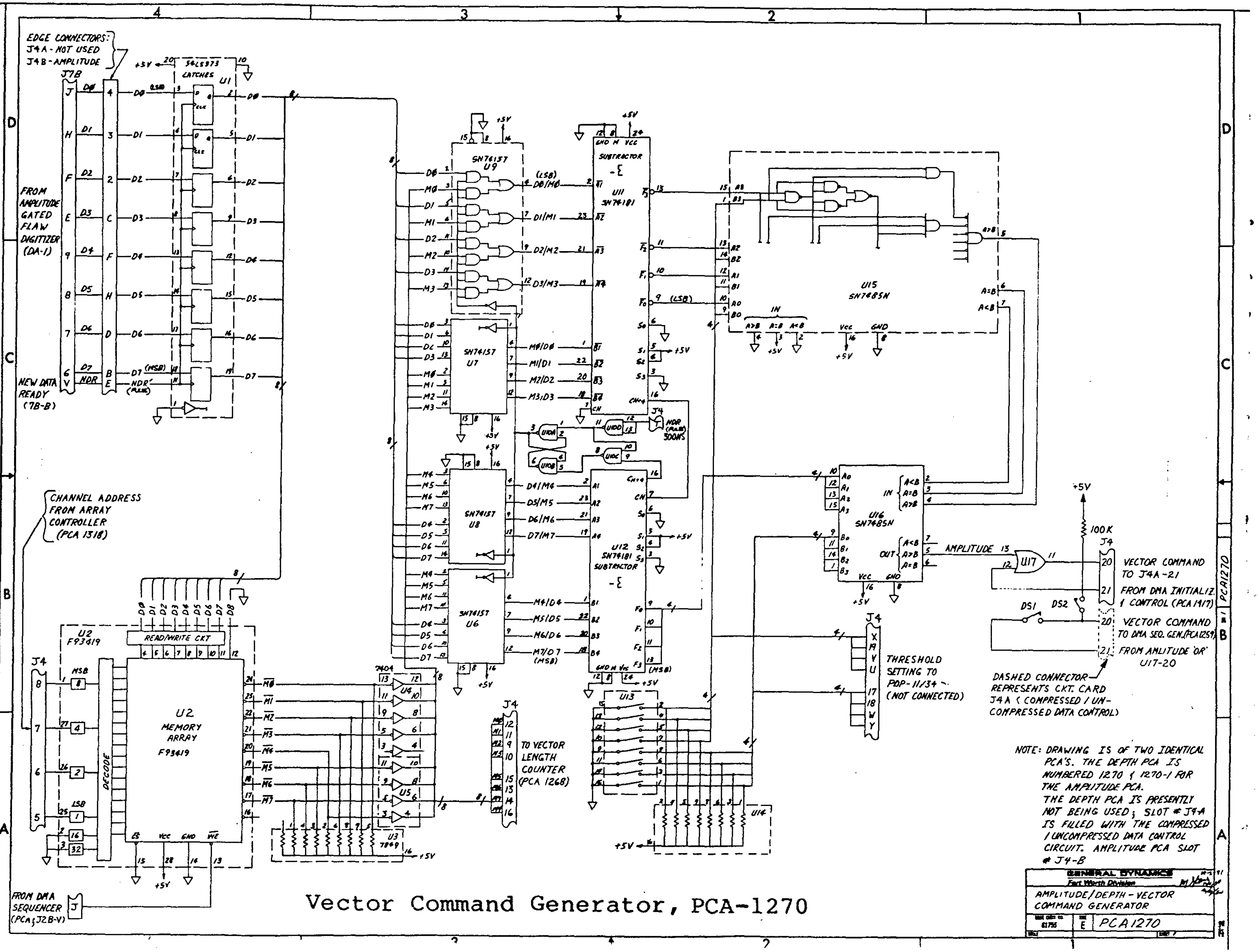
S-80 Differential Line Driver/Receiver, PCA-1264-1



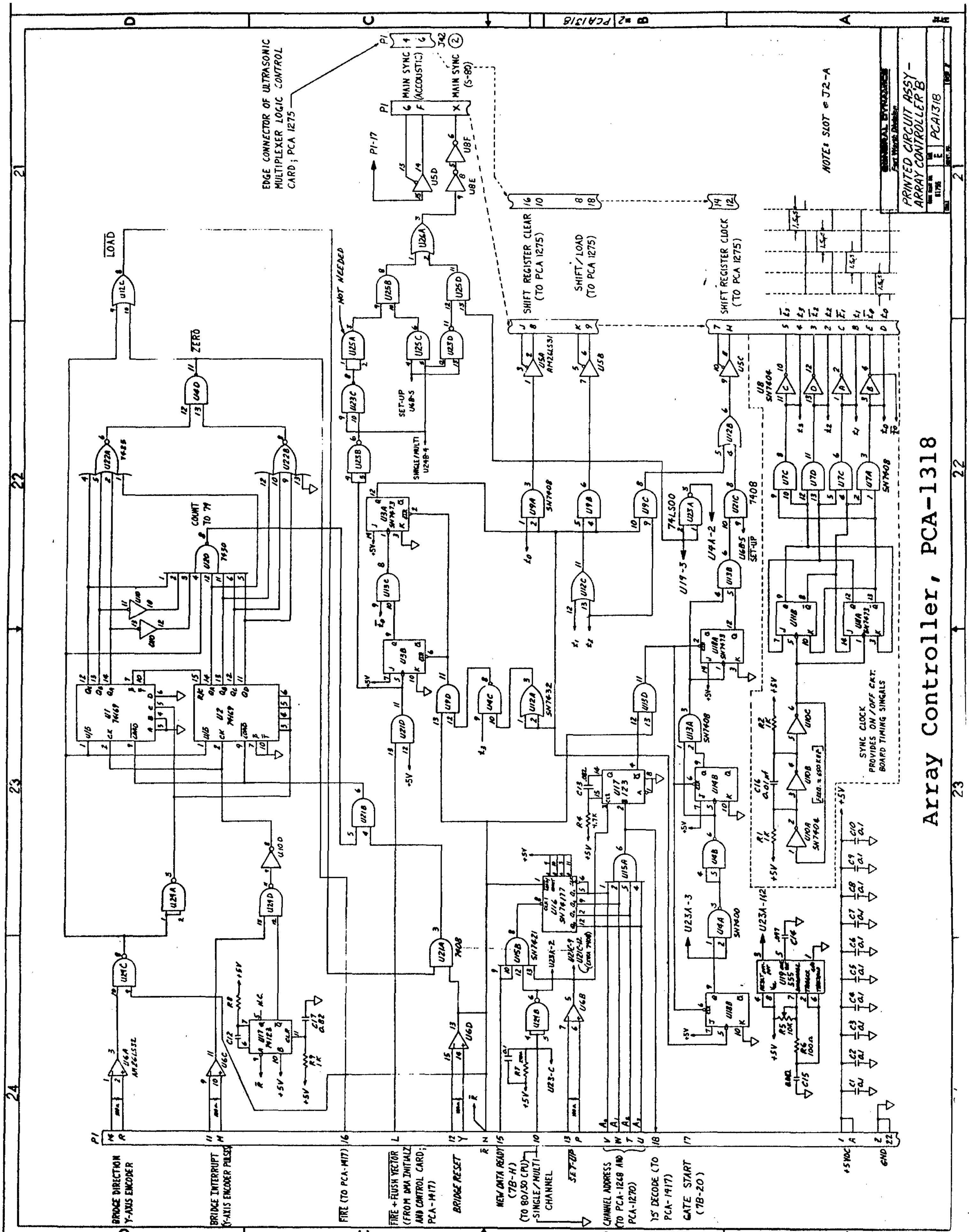
GATED OSCILLATOR DIAGRAM

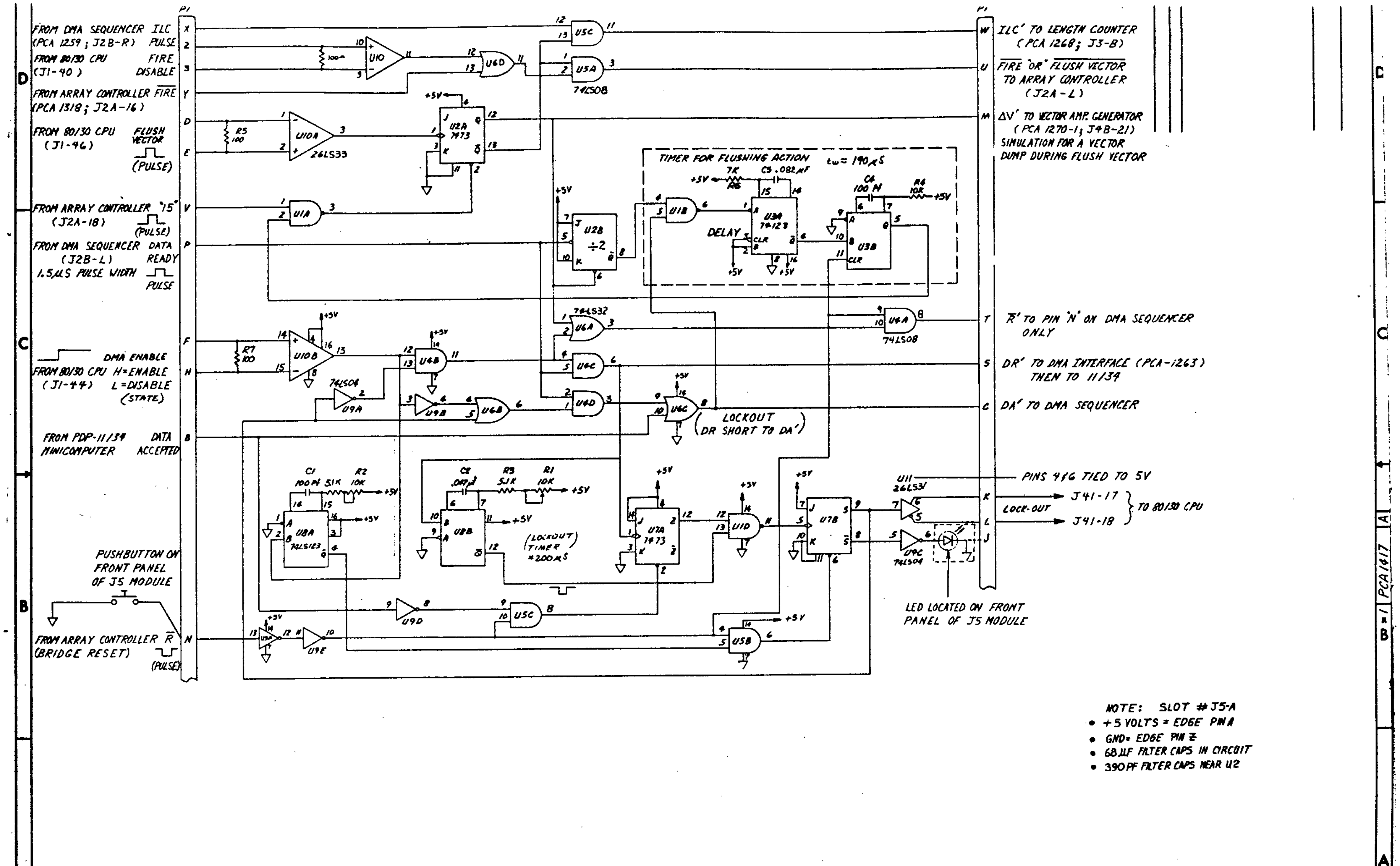


Vector Length Counter and
Data Multiplexer, PCA-1268-1



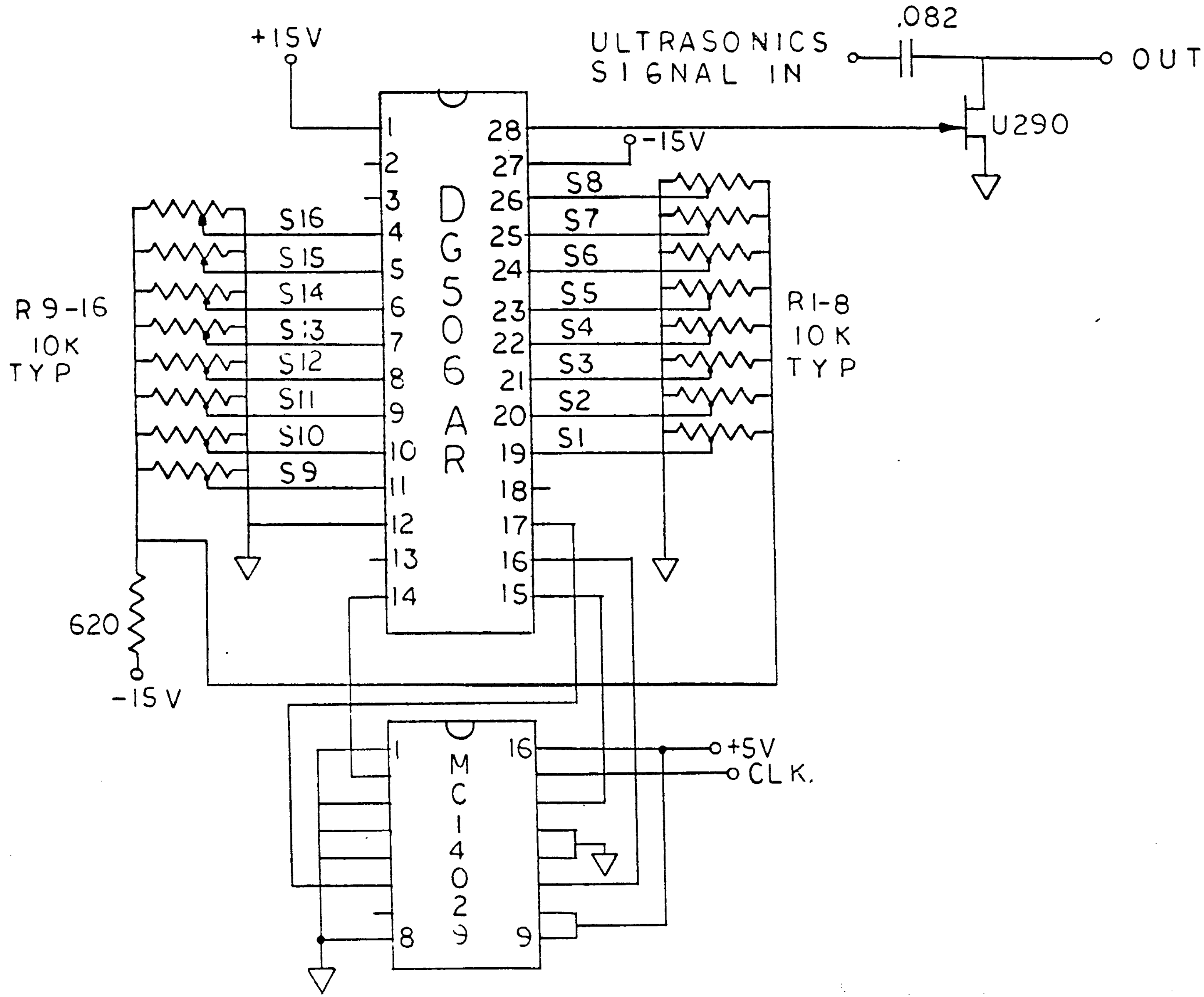
Vector Command Generator, PCA-1270


Array Controller, PCA-1318
PRINTED CIRCUIT ASSY - ARRAY CONTROLLER B
PCA1318
EDGE CONNECTOR OF ULTRASONIC MULTIPLEXER LOGIC CONTROL CARD; PCA 1275
MAIN SYNC (ACCOUSTIC)
MAIN SYNC (S-80)
SHIFT REGISTER CLEAR (TO PCA 1275)
SHIFT/LOAD (TO PCA 1275)
SHIFT REGISTER CLOCK (TO PCA 1275)
NOTE: SLOT @ J2-A
NOT NEEDED
LOAD
ZERO
COUNT TO 79
SYNC CLOCK PROVIDES ON/OFF CKT. BOARD TIMING SINGALS
BRIDGE DIRECTION Y-AXIS ENCODER
BRIDGE INTERRUPT X-AXIS ENCODER PULSES
FIRE (TO PCA-1417)
FIRE + FLUSH VECTOR (FROM DMA INITIALZ AND CONTROL CARD; PCA-1417)
BRIDGE RESET
NEW DATA READY (7B-H) (TO 80/30 CPU)
SINGLE/MULTI CHANNEL
SET-UP
CHANNEL ADDRESS (TO PCA-1248 AND PCA-1270)
Y5 DECODE (TO PCA-1417)
GATE START (7B-20)
+5VDC
GND

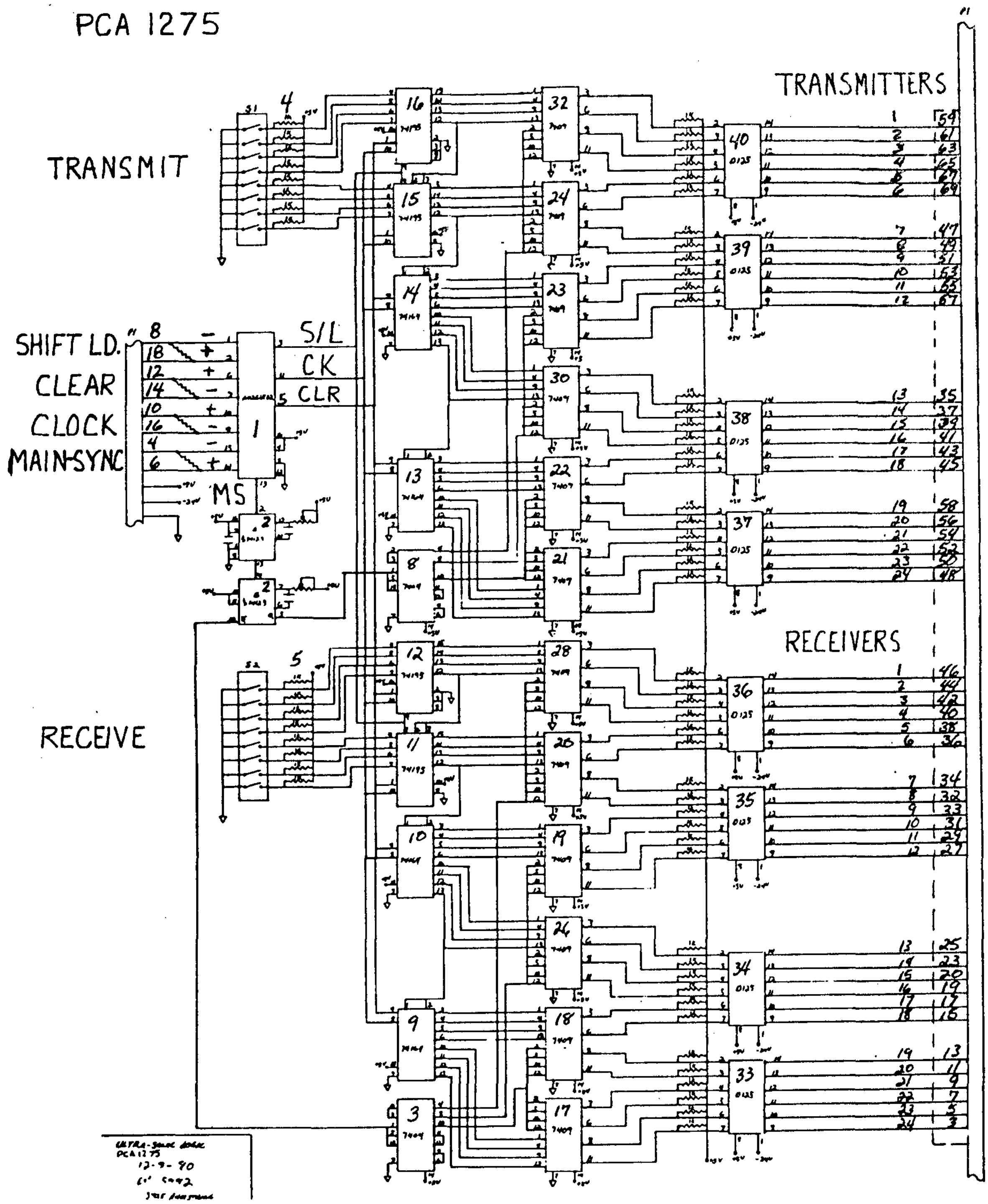


Direct Memory Access (DMA) Initialization and Control, PCA-1417

GENERAL DYNAMICS
CIRCUIT CARD ASSY — DMA INITIALIZATION & CONTROL
PCA 1417



MULTIPLEX ATTENUATOR DIAGRAM



MULTIPLEXER DIGITAL LOGIC BOARD DIAGRAM

☆U.S.Government Printing Office: 1985 — 559-065/20738